REGIONAL PLANNING
PART VI - UPPER RIO GRANDE

FEBRUARY - 1938

NATIONAL RESOURCES COMMITTEE

REGIONAL PLANNING

PART VI—THE RIO GRANDE JOINT INVESTIGATION

IN THE

UPPER RIO GRANDE BASIN

IN

COLORADO, NEW MEXICO, AND TEXAS

1936-1937

PUBLISHED IN TWO VOLUMES

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VOL. II. MAPS

NATIONAL RESOURCES COMMITTEE

FEBRUARY 1938

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NATIONAL RESOURCES COMMITTEE

INTERIOR BUILDING

WASHINGTON

December 23, 1937.

The PRESIDENT,
The White House,
Washington, D. C.

MY DEAR MR. PRESIDENT:

We have the honor to transmit herewith the Report of the Rio Grande Joint Investigation, which constitutes Part VI of the series on regional planning activities and progress.

The Rio Grande Investigation was undertaken at the request of the States of Colorado, New Mexico, and Texas with the National Resources Committee serving as a channel for the organization of surveys and studies by appropriate Federal and State bureaus. It is a notable example of cooperative endeavor financed partly through an allocation from the Public Works Administration but with substantial contributions from the three States and some four or five Federal agencies.

Sincerely yours,

HAROLD L. ICKES,
Secretary of the Interior, Chairman.

HARRY H. WOODRING,
Secretary of War.
HENRY A. WALLACE,
Secretary of Agriculture.
DANIEL C. ROPER,
Secretary of Commerce.
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Secretary of Labor.

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Harlan H. Barrows, *Chairman*

Frank Adams

November 30, 1937.

Mr. Frederic A. Delano,
Chairman, Advisory Committee,
National Resources Committee,
Washington, D. C.

Dear Mr. Delano:

We submit herewith the report of the Rio Grande Joint Investigation, and recommend that it be published.

The report is of national as well as regional importance. Primarily, it forms the factual base on which a reasonable plan for the future development of the water resources of the Upper Rio Grande Basin may be constructed. In addition, it illustrates a new and pioneering method for the preparation of water plans in interstate drainage basins of the United States.

The cooperating State and Federal agencies are to be congratulated upon their skill and initiative in organizing a large-scale investigation without administrative precedent. The members of the consulting board have displayed rare ability in planning and guiding the work.

From these efforts may come a satisfactory solution of the present critical Rio Grande problems, and the experience on which plans for other interstate drainages may be undertaken.

Respectfully submitted.

Abel Wolman

Chairman, Water Resources Committee

Chief Engineer, Maryland State Department of Health

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Sherman M. Woodward,
Chief Water Control Planning Engineer,
Tennessee Valley Authority.

AUGUST 10, 1937.

MR. ABEL WOLMAN,

Chairman, Water Resources Committee.

DEAR MR. WOLMAN: There is transmitted herewith the report of the Rio Grande joint investigation, conducted under the authority of the National Resources Committee through its Water Resources Committee. The investigation was undertaken at the request of the Rio Grande compact commissioners of Colorado, New Mexico, and Texas. It was carried out in cooperation with the United States Geological Survey, the Bureau of Reclamation, the Bureau of Agricultural Engineering, and the Bureau of Plant Industry, with material assistance from the Bureau of Indian Affairs, the Resettlement Administration, and Soil Conservation Service. Various other organizations, Federal, State, and local, helped by providing services, materials, records, office or laboratory space, and the like. The requisite funds were provided by the three States and several Federal agencies.

The basin of the Rio Grande above Fort Quitman, Tex., presents in clear relief the nature and magnitude of the physical, legal, economic, and social conditions and relationships involved in the use of the land and water resources of a large interstate drainage area in Western United States. It also furnishes an example of some of the involvements likely to arise when an important river is international as well as interstate in character.

For three-quarters of a century the Western States have been creating and perfecting, gradually but definitely, the legal principles and the social institutions needed where irrigation is the chief basis of economic life. Although much remains to be accomplished, none of the Western States lacks authority for adequate control and administration of intrastate waters, whether surface waters or underground waters. On the other hand, the authority of a State to control and administer interstate waters is limited. If the claims of two or more States to such waters are in conflict, the States may settle the controversy through negotiation of an interstate compact or may have recourse to the Supreme Court of the United States for adjudication of the differences at issue. The weight of public opinion favors the interstate compact. Moreover, the Supreme Court repeatedly has taken a friendly attitude toward the compact mode of action.

In the case of the upper Rio Grande, lack of adequate factual data proved to be an insurmountable obstacle to success by the compact method, notwithstanding earnest efforts by the interested States to reach an agreement. Finally, a suit was begun in the Supreme Court of the United States with a view to adjusting differences between the users of Rio Grande waters in New Mexico and Texas. This action was taken, however, prior to the initiation of the cooperative fact-finding investigation.

The Rio Grande joint investigation constituted a unique approach to the underlying problems of a grave controversy over an interstate river. For the first time the States engaged in such a controversy joined with one another and with the Federal Government in an endeavor to find a satisfactory basis for the allocation of the waters of a river through the assembly of the factual data essential to such an allocation. The cordial willingness with which the official representatives of Colorado, New Mexico, and Texas entered into the undertaking exemplified constructive statesmanship. The precedent they established should facilitate negotiations relating to other interstate streams. Each of these States is vitally concerned with its own welfare, yet in the Rio Grande joint investigation each recognized its obligation to its sister States; each accepted the principle that an equitable adjustment of conflicting interests in the waters of the river is imperative.

The consulting board which has been responsible to the Water Resources Committee for the organization and conduct of the investigation is grateful to all who took part in it. The participating agencies cooperated superbly, and the field organization worked enthusiastically, apparently sensing in the enterprise a great opportunity and a great challenge. Especially appreciative are we of the high ability and fine judgment displayed by the engineer in charge, Mr. Harlowe M. Stafford. We also commend the splendid services of the associate engineer, Mr. Fred C. Scobey.

It is our conviction that the report transmitted herewith furnishes a sound factual basis for an apportionment of the waters of the river above Fort Quitman that would be fair and just to each of the States and to its water users dependent on the river. It is our conviction also that the report furnishes a sound basis for the development of a plan by which the water that may be made available by salvage, storage, importation, and other means would render full service and for the formulation of a program looking to construction of the requisite works in an orderly, balanced manner. We commend the report to the careful consideration not only of the Water Resources Committee and the National Resources Committee, but also of the States, whose further cooperation will be necessary to reach an agreement with respect to the problems of the river, and of the administration and the Congress, whose assistance will be needed in providing the physical works involved in a workable solution of those problems.

Very sincerely yours,

Frank Adams,
Harlan H. Barrows,
Chairman, Consulting Board,
Rio Grande Joint Investigation.

 Upper Rio Grande Basin.

THE RIO GRANDE JOINT INVESTIGATION IN THE UPPER RIO GRANDE BASIN

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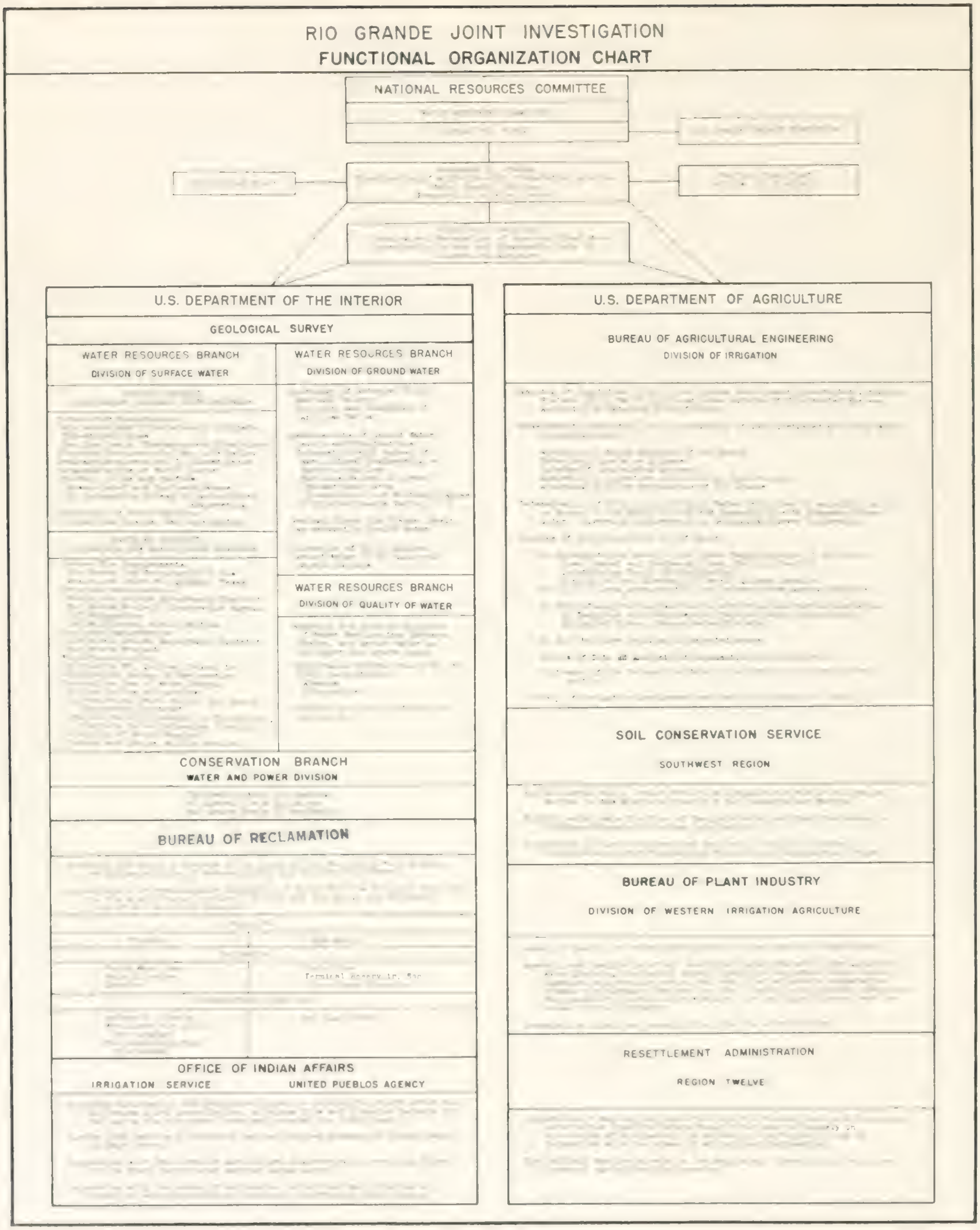
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U.S. DEPARTMENT OF THE INTERIOR
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DIVISION OF SURFACE WATER
WATER RESOURCES BRANCH
DIVISION OF GROUND WATER
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RESETTLEMENT ADMINISTRATION
REGION TWELVE

PART I
GENERAL REPORT OF THE RIO GRANDE JOINT INVESTIGATION

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ORGANIZATION

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SPECIAL CONSULTANT IN REVIEW OF FINDINGS

J. C. Stevens

COOPERATING AGENCIES

FEDERAL AGENCIES

Many Federal agencies have cooperated on this investigation as shown by the organization chart.

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Office of New Mexico State Engineer—Thomas M. McClure, *State Engineer.*

THE RIO GRANDE COMPACT COMMISSION

S. O. Harper, *Chairman, Commissioner for the United States.*
M. C. Hinderlider, *Commissioner for Colorado.*
Thomas M. McClure, *Commissioner for New Mexico.*
Frank B. Clayton, *Commissioner for Texas*

ACKNOWLEDGMENTS

In the course of the Rio Grande Joint Investigation much valuable cooperation and assistance have been given by many individuals and by various public and private agencies.

Particular and appreciative mention is made of liberal contributions of office and laboratory space by the custodian of the United States courthouse at Santa Fe, by the New Mexico College of Agriculture and Mechanic Arts at State College, by the University of New Mexico at Albuquerque, by the office of the United States Weather Bureau at Albuquerque, and by the Adams State Teachers College at Alamosa, Colo.

In addition to thankful acknowledgment of the contributions and assistance of all the cooperating agencies and officials noted elsewhere in this report, appreciation is expressed to the representatives and engineers of the American Section, International Boundary Commission, El Paso, the Rio Grande Reclamation Project, El Paso, the Middle Rio Grande Conservancy District, Albuquerque, and the Rio Grande Water Users Association, San Luis Valley, for furnishing or making it possible to obtain a great deal of valuable data and information.

Available space precludes individual mention of all who have furnished data and assistance. These contributions are appreciated and are gratefully acknowledged.

PART I

SECTION 1.—INTRODUCTION AND SUMMARY

The Upper Rio Grande Basin

This investigation is concerned with the water problems of the portion of the Rio Grande drainage area which lies above Fort Quitman, Tex., situated about 80 miles southeast of El Paso. Known generally as the Upper Rio Grande Basin, it comprises about 34,000 square miles. The total drainage area of the Rio Grande is about 175,000 square miles.

Rio Grande is an interstate and an international stream. It rises in Colorado and flows southward for more than 400 miles across New Mexico. After leaving New Mexico, it forms the boundary between Texas and the Republic of Mexico for about 1,250 miles to its mouth. The total length of the river is about 1,800 miles.

With respect to usage of water and the problems concerned with that usage, the river is divided into two distinct sections at Fort Quitman, or at the narrow gorge a few miles below. Above this nearly all the water of the river is being consumed by irrigation in Colorado, New Mexico, Texas, and Mexico. Below, in the lower basin, the river develops its flow mainly from tributaries in Mexico.

In the Upper Rio Grande Basin, including parts of Colorado and New Mexico, and a very small part of Texas, more than 99 percent of the water supply comes from Colorado and New Mexico in about equal amounts.

In accordance with natural divisions, the upper basin comprises three principal areas: the San Luis section in Colorado, the Middle section in New Mexico, and the Elephant Butte-Fort Quitman section in New Mexico, Texas, and Mexico. These are indicated on the general map, plate 1.

The San Luis section comprises the basin of Rio Grande in Colorado, the principal agricultural area of which is the San Luis Valley. This is a broad plain of smooth topography, surrounded by mountains except on the south near the Colorado-New Mexico State line, where the river has cut an outlet for the southern portion of the valley. The northern portion is not thus drained and is known as the Closed Basin. The valley floor ranges in altitude from 7,440 to 8,000 feet and the surrounding mountains from 10,000 to more than 14,000 feet.

The Middle section comprises the basin of Rio Grande in New Mexico above San Marcial. Below the Colorado-New Mexico State line, Rio Grande flows through a canyon for about 70 miles to Embudo. The "Middle Valley" comprises the long narrow territory adjacent to the river from Embudo south to San Marcial, a distance of about 200 miles. It is a succession of narrow valleys separated by rock canyons or merely short "narrows." Of these subvalleys, Santo Domingo, Albuquerque, Belen, and the northern two-thirds of Socorro constitute the area of the Middle Rio Grande Conservancy District. Altitudes in the Middle Valley range from 5,590 feet in Espanola, the uppermost subvalley, to 4,450 feet at San Marcial, at the lower end of Socorro Valley.

The Elephant Butte Reservoir of the Rio Grande Project, United States Bureau of Reclamation, occupies the immediate river valley from San Marcial narrows to Elephant Butte, a distance of about 40 miles. What is here designated as the Elephant Butte-Fort Quitman section includes the reservoir area and the wide plains and long strips of land adjacent to the river from Elephant Butte to Fort Quitman, some 210 miles, of which 130 miles are above El Paso. Like the Middle section, Elephant Butte-Fort Quitman section is a succession of valleys separated by canyons and narrows. Of these valleys, Rincon, Mesilla, and the northern half of El Paso Valley on the Texas side of the river comprise the area of the Rio Grande project. Included in the southern half of El Paso Valley, on the Texas side, is the area of the Hudspeth County Conservation and Reclamation District. The El Paso Valley area southwest of the river is in Mexico. Altitudes in the Elephant Butte-Fort Quitman section range from 4,200 feet at Elephant Butte to 3,710 at El Paso and 3,400 at Fort Quitman.

Historical Background

The valley lands of the Upper Rio Grande Basin are devoted almost entirely to agriculture. Because of scant precipitation throughout all valleys of the basin, irrigation is required for the successful growing of crops. Irrigation along the Rio Grande goes back to an unknown date when it was initiated by Pueblo Indians or their ancestors.

Recorded history of the Rio Grande Valley begins with its discovery by Coronado in 1540. Later, in the seventeenth and eighteenth centuries, Spanish colonization in the Middle and Elephant Butte-Fort Quitman sections was accompanied by an expansion of irrigation.

Irrigation by white men in San Luis Valley was begun in the early 1850's, but it was not until about 1880 that extensive development occurred. Then, in the decade 1880–90, accelerated activity resulted in most of the large canal systems and other irrigation works that exist there today.

In the early 1890's water shortages began to occur along the Rio Grande in Mesilla and El Paso Valleys and people near Juarez, across the river from El Paso, complained to the Mexican Government. The latter filed a claim for damages against the United States, alleging that the water shortages were due to increasing diversions from the river in Colorado and New Mexico. The United States Department of State then instituted an investigation of the situation through the International Boundary Commission, and the outcome was the "embargo" of 1896 and the Mexican Treaty of 1906. The "embargo" was an order by the Secretary of the Interior of the United States which prevented further irrigation development of any magnitude in the Rio Grande Basin in Colorado and New Mexico through suspension of all applications for rights-of-way across public lands in those States for use of Rio Grande water. With some modification in 1907, this embargo remained in effect until May 1925, when it was lifted. Under the terms of the Mexican Treaty, the United States guaranteed to Mexico, in return for relinquishment of all claims for damages, an annual delivery in perpetuity in the Rio Grande at the head of the Mexican Canal near El Paso, of 60,000 acre-feet of water.

Both to insure fulfillment of the Mexican Treaty and to develop a reclamation project in the Elephant Butte-Fort Quitman section, the United States provided for construction of the Elephant Butte Reservoir by the Bureau of Reclamation. This reservoir, with an original capacity of 2,639,000 acre-feet, together with other initial works for the Rio Grande Project, was completed in 1916.

The embargo was opposed in Colorado, since even by 1896 the irrigated lands in San Luis Valley used all the available natural flow of Rio Grande and its tributaries in that valley. Storage appeared necessary not only for further development but even to maintain existing developments. But storage of any magnitude was impossible under the embargo. The effort of Colorado to secure permission to build reservoirs thus began early, and has continued to date.

About 1918, active interest developed in reclamation in the Middle Valley. Much land there had become badly seeped and it was affirmed that over a period of many years there had occurred a serious decline and failure of the irrigated acreage. This was attributed not only to a decrease in the flow of the river and to a shortage of water for irrigation but also to resultant deposition of silt, aggradation of the river bed, and elevation of the water table under the valley floor. It was affirmed that the decrease in river flow was due to depletions in San Luis Valley.

The Rio Grande Compact

With the interstate situation becoming increasingly aggravated, it was suggested that a commission be named to study the water supply and to draft a compact between the States affected, under which an equitable allocation of the waters of the upper Rio Grande would be made. Accordingly the legislatures of Colorado and New Mexico enacted statutes in 1923 under which the respective Governors appointed commissioners. The President named a commissioner to represent the United States. Later, a commissioner for Texas was designated by the Governor of that State.

Negotiations looking to a compact were started, but they proceeded slowly, pending the outcome of engineering investigations instituted by Colorado and by New Mexico. Finally, after an extended session of the commission in January 1929, a compact was concluded which became effective upon its ratification, later that year, by the legislatures of the three States and by the Congress. This compact does not, however, set up an allocation of Rio Grande waters. It is, moreover, a temporary measure. Its principal articles provide, in effect, that during the period of the compact neither Colorado nor New Mexico will cause or suffer the water supply in Rio Grande to be impaired by new or increased diversions or storage unless and until such depletion is offset by increase of drainage return; that the three States will maintain certain gaging stations and exchange the records therefrom; and that before the expiration of the compact a commission shall be constituted to conclude a permanent compact providing for the equitable apportionment of the water of Rio Grande among the States. It sets up the desirability of a drain to the river from the "closed basin" in Colorado and of a reservoir on Rio Grande at or near the Colorado-New Mexico State line, as features in the economic development and conservation of the waters of the basin and as helpful factors in reaching an accord among the States. In it the conviction is expressed that the United States should construct the Closed Basin drain and the State Line reservoir without cost to the States by reason of its obligation under the Mexican Treaty, in fulfillment of which it has, in effect, made an annual draft of 60,000 acre-feet on Colorado, New Mexico, and Texas.

The original expiration date of this compact was June 1, 1935, and before that time the commission met to conclude, if possible, a permanent compact. Although many proposals were made, no agreement was reached; further basic data on the supply and use of water were needed. As a result, the effective period

of the temporary compact was extended to June 1, 1937. Recommendation for its further extension to October 1, 1937, was made by the Rio Grande Compact Commission sitting in Santa Fe March 4, 1937.

Previous Investigations

Reference has been made to previous engineering investigations of the supply and use of water in the Upper Rio Grande Basin. With controversies over the use of the water increasing with passing years, many investigations naturally have been undertaken and a mass of data and information has been accumulated. Unfortunately, few of these investigations have been reported in printed form. In many instances, the investigations were made to determine only the water situation for particular localities and the results were reported in typewritten form to some local, State, or Federal agency. In the bibliography accompanying this report as Appendix C there is a selected list of published and unpublished reports that have been made. Some previous investigations of basin-wide significance are noted in the following paragraphs.

In 1896 the International Boundary Commission caused an investigation to be made of the water supply and irrigation development in the Rio Grande Basin above Fort Quitman, Tex. The report of this investigation, best known as the Follett report, after W. W. Follett, who made it, covers comprehensively and in detail the stream flow, irrigated areas, canal systems, ditches, and diversions for every section of the basin from San Luis Valley to El Paso. This is published in United States Senate Document 229, Fifty-fifth Congress, second session.

In 1904 an investigation of the geology and water resources of the San Luis Valley was made by C. E. Siebenthal of the United States Geological Survey; the results were published as Water Supply Paper No. 240.

In 1910 James A. French, engineer for the Bureau of Reclamation, undertook an investigation to establish the facts concerning the "past, present, and contemplated irrigation near the headwaters of the Rio Grande in Colorado and to determine the effects of such developments on the normal flow of the Rio Grande below the Colorado-New Mexico State line." In the same year, H. W. Yeo, also an engineer with the Bureau of Reclamation, was assigned to a detailed investigation of the extent of irrigation in the Rio Grande Valley of New Mexico. The reports of these investigations were submitted to the Bureau of Reclamation.

In 1912 and 1913 Jay D. Stannard of the Bureau of Reclamation and D. G. Miller of the Drainage Investigations, Department of Agriculture, made an investigation and reported on "Drainage and Water Development in San Luis Valley, Colo."

In 1919 Engineers Harold Conkling and E. B. Debler reported to the Bureau of Reclamation on an extensive investigation made to determine the water supply, irrigation development, and possibilities of future development in San Luis Valley, in the Middle Rio Grande Valley, and under the Rio Grande Project.

In 1924 Debler made an investigation and report to the Bureau of Reclamation on the water supply and requirements of the Rio Grande Project.

Under a cooperative agreement between the Middle Rio Grande Conservancy District and the Bureau of Reclamation, Engineers Debler and Elder carried on an extensive investigation in the Middle Valley from 1926 to 1928. The primary purpose was to determine the probable effect upon the water supply for the Rio Grande project of the construction and operation of the proposed works of the Middle Rio Grande Conservancy District. A preliminary report was made in December 1927, and the final report in 1932.

The report of J. L. Burkholder, chief engineer of the Middle Rio Grande Conservancy District, covering the district's investigations and the final plan for flood control, drainage, and irrigation within its limits was published in 1929.

Beginning soon after provision was made in 1923 by Colorado and New Mexico for the appointment of their representatives on the Rio Grande Compact Commission and continuing over much of the period to date, investigations have been carried on under the direction of the Colorado and New Mexico State Engineers. The primary purpose has been the compilation of information and data needed by the commissioners in endeavoring to work out a compact between the States. The investigations of New Mexico covered the San Luis section, as well as the Middle section, and much of the data and results is included in reports, unpublished, of C. R. Hedke, 1924 and 1925; E. P. Osgood, 1928; R. G. Hosea, 1928; and H. W. Yeo, 1928 and 1931. In addition to the San Luis section, the investigations of Colorado included a study of the use of water, drainage, and wastes in the Elephant Butte-Fort Quitman section. The data and results of the work of Colorado are largely covered in unpublished reports to the State Engineer by R. I. Meeker from 1924 to 1928, and by R. J. Tipton from 1924 to 1935.

In 1935 a committee of consulting engineers, O. V. P. Stout, F. H. Fowler, and E. B. Debler, made an investigation and report to the Federal Emergency Administration of Public Works on the probable water yield, cost, and feasibility of the "sump drain", a project to conduct to the Rio Grande the recoverable waters of the sump area in the Closed Basin of San Luis Valley.

The Present Investigation

Origin and History

During the last few years there has been much activity in the Upper Rio Grande Basin in the promotion of water utilization projects for which Federal funds have been sought. In 1935, the irrigation and drainage works of the Middle Rio Grande Conservancy District, including El Vado Reservoir on Rio Chama, a tributary of Rio Grande, were completed and put in operation. District bonds for this construction were purchased by the Reconstruction Finance Corporation. The Rio Grande Project is a Federal project and a conflict of Federal interests developed. Moreover, with the available water resources of the Upper Rio Grande Basin apparently fully appropriated, the approval of any new projects involving additional drafts upon these resources seemed to point inevitably to further conflict of Federal interests and to violation of the Rio Grande compact.

Appreciating this situation and spurred by the need for prompt action to avoid uncoordinated development of water utilization projects, the National Resources Committee appointed a board to review the situation and to recommend an appropriate procedure. Pursuant to recommendations of this Board and as an immediate result of them, the President issued the following executive memorandum:

THE WHITE HOUSE,
Washington, September 23, 1935.

To Federal agencies concerned with projects or allotments for water use in the Upper Rio Grande Valley above El Paso:

From information secured by the National Resources Committee, it appears that in view of the practically complete present appropriation of reliable water supply in the basin of the Rio Grande above El Paso, Federal investments in this region which promote increased use of water tend to impair the security of extensive prior investments of Federal funds, to violate the terms of an interstate compact to which the Federal Government is a party, and to promote social insecurity in the region.

Please instruct appropriate officials of your agency in Colorado and New Mexico, as well as in Washington, or in other supervisory offices, not to approve any application for a project involving the use of Rio Grande water without securing from the National Resources Committee a prompt opinion on it from all [illegible] points of view.

(Signed) FRANKLIN D. ROOSEVELT

Following out a further recommendation of the Board of Review, the National Resources Committee proposed a conference with the Rio Grande compact commissioners and other representatives of Colorado, New Mexico, and Texas to see if there might be any way in which the National Resources Committee and the three States could cooperate in gathering the facts that might be helpful in arriving at a solution of the interstate water problem on the Rio Grande above Fort Quitman. The conference was held at Santa Fe, December 2–3, 1935, and resulted in the adoption of the following resolution by the Rio Grande Compact Commission:

Whereas, The Rio Grande Compact Commission was created for the purpose, among others, of making equitable division of the waters of the Rio Grande above Fort Quitman, Tex., between the States of Colorado, New Mexico, and Texas, and

Whereas, The National Resources Committee has expressed its willingness to cooperate, if practicable, with the Rio Grande Compact Commission in the collection of relevant basic data,

Now, therefore, be it resolved, That the National Resources Committee, through its Water Resources Committee, be requested, in consultation with the members of the Rio Grande Compact Commission, to arrange immediately for such investigation (1) of the water resources of the Rio Grande Basin above Fort Quitman, (2) of the past, present and prospective uses and consumption of water in such Basin in the United States, and (3) of opportunities for conserving and augmenting such water resources by all feasible means, as will assist the Rio Grande Compact Commission in reaching a satisfactory basis for the equitable apportionment of the waters of the Rio Grande Basin in the United States above Fort Quitman, as contemplated by such Rio Grande compact.

In making this request the Rio Grande Compact Commission, and its individual members, declare it to be their desire to cooperate and assist in such investigation in all ways within their power, and it further declares that, through its individual members, it will seek to obtain the allotment of State funds, or services, or both, for the purposes of the investigation in such amounts as will equitably distribute the costs thereof between the Federal Government and the member States of Colorado, New Mexico, and Texas.

It is understood that the cooperative investigation requested herein shall be limited to the collection, correlation, and presentation of factual data, and shall not include recommendations, except upon request of the Rio Grande Compact Commission, based upon the unanimous agreement of its members.

It is further understood that the said investigation shall be in harmony with the spirit and intent of the Rio Grande compact, and nothing herein contained shall be taken to be a modification or alteration of the terms thereof.

Pursuant to this resolution, funds were allocated by the Federal Emergency Administration of Public Works to the National Resources Committee for the purpose of the investigation, on condition that certain additional funds would be contributed by the three States and by certain other Federal agencies. At a second Santa Fe conference early in February 1936 the agreements for contribution of funds were successfully consummated and plans for the investigation were agreed upon. Field work was started in April and continued throughout 1936. In connection with completion of studies of storage and transmountain diversions, field work continued through July 1937.

Purpose and Scope

The prime purpose of the Rio Grande joint investigation was to determine the basic facts needed in arriving at an accord among the States of Colorado, New Mexico, and Texas on an equitable allocation and use of Rio Grande water in the future development of the

upper basin. In general, the essential facts sought are those relating to the available water supply, the water uses and requirements, and the possibilities of additional water supplies by storage, importations and salvage of present losses and wastes.

With respect to the supply of water, the investigation has included measurements and records of stream flow at all essential points on the Rio Grande and its tributaries, and on San Juan Basin streams as pertaining to possible transmountain diversions to the Rio Grande Basin. Many new gaging stations have been established.

As relating both to water supply and use, the investigation has included measurements of ground water levels and fluctuations in San Luis Valley and throughout the Middle Valley, an inventory of the number and discharge of wells in the artesian basin of San Luis Valley, and a program of sampling and analysis of surface and underground waters throughout the basin to determine their chemical quality.

The investigation to determine water uses and requirements has included measurements and records of canal diversions in three principal areas—San Luis Valley, Middle Rio Grande Conservancy District, and Rio Grande Project; measurements of drainage and waste in selected areas; complete mapping, classification and determination in detail of acreages, according to canal systems and geographic and political subdivisions, of the vegetative cover on all irrigated lands and other water-consuming areas throughout the basin; the preparation of base maps, both general and in detailed units, covering all requisite geographic, artificial and hydrographic features for the entire upper basin; measurements of the consumptive use of water by crops and native or nonbeneficial vegetation by means of experimental studies, including soil moisture determinations, observation of ground water fluctuations, and the growing of plants in metal tanks, and by complete measurements of all inflow and outflow of water on selected representative areas in the San Luis, Middle, and Elephant Butte-Fort Quitman sections; a study of the consumptive use of water based on past records; and a review of the history of irrigation development in the upper basin.

As to the possibility of additional water supplies by salvage of present losses and wastes, determination of the data needed resulted largely from the investigations outlined in preceding paragraphs. With respect to additional supplies by storage and importation, the investigation has included the survey, examination, analysis, and preliminary design of four major storage projects and of four separate projects for diversion of San Juan Basin waters to the Rio Grande Basin. The storage projects include the Wagon Wheel Gap and Vega-Sylvestre on the upper Rio Grande, one or more sites on the Conejos River, the principal Rio Grande tributary in Colorado, and the State Line site on the Rio Grande near the Colorado-New Mexico State line. The transmountain diversion projects include the Animas-Rio Grande, Weminuche Pass, and San Juan-South Fork Rio Grande in Colorado, and the San Juan-Chama in Colorado and New Mexico. With reference to the diversion projects, the investigation has included a study of their effect on San Juan Basin development, and a survey of initial, terminal, and other storage opportunities on the conduit lines.

To accomplish this investigation efficiently, expeditiously, and impartially within the period available, it was proposed by the consulting board of the National Resources Committee and approved by the State representatives that the work should be assigned to and divided among three major Federal agencies by cooperative agreements between the National Resources Committee and those agencies. It was agreed further that the consulting board and an engineer in charge with headquarters at Santa Fe, N. Mex., should be responsible to the National Resources Committee for the general coordination and conduct of the work and for the final report of the investigation.

In accordance with the cooperative agreements, the Geological Survey has carried out the measurements of stream flow, drainage, waste, and diversions, the studies of ground water, and the sampling and analyses in the quality of water investigation; the Bureau of Agricultural Engineering has carried on the mapping and classification of vegetative cover, the compilation and segregation of irrigated acreages and other water-consuming areas, the study of consumptive use of water, and review of the history of irrigation development; and the Bureau of Reclamation has been responsible for the investigation and report on storage and transmountain diversion projects.

Supplementary cooperative agreements were also effected for contributions of money or services, or both, between the National Resources Committee and the Bureau of Plant Industry, the Soil Conservation Service, the Resettlement Administration, and the Office of Indian Affairs, between the Geological Survey and the States of Colorado and New Mexico; and between the Bureau of Agricultural Engineering and these States. The cooperation of the Soil Conservation Service and the Resettlement Administration has been largely in the nature of mapping and the provision of maps and data which tied in closely with the work of the Bureau of Agricultural Engineering; that of the Office of Indian Affairs has been associated with the investigations of both the Geological Survey and the Bureau of Agricultural Engineering; that of the Bureau of Plant Industry has comprised the assembly and compilation of all analytical data of the quality of water investigation,

together with preparation of the summary and interpretive digest of those data. Informal cooperation has been extended by many other Federal, State, and local agencies throughout the Upper Rio Grande Basin. The reports of the data obtained and studies made by the Geological Survey, the Bureau of Agricultural Engineering, the Bureau of Plant Industry, and the Bureau of Reclamation under the Rio Grande Joint Investigation are incorporated in parts II, III, IV, and V, respectively, of this report.

The Problem

The essential water problem of the Upper Rio Grande Basin is the division of the water supply between the San Luis section of Colorado, the Middle section of New Mexico, and the Elephant Butte-Fort Quitman section of New Mexico and Texas, with due consideration to past and present uses and requirements and to future development. Elements involved are also the salvage of recoverable wastes and, to the extent feasible, the importation of water from outside the Rio Grande Basin.

As stated by Colorado, its major problem is the provision of storage capacity sufficient to regulate stream flow so that the supply of water may parallel and meet the irrigation demand of the San Luis Valley lands that are now irrigated and for which irrigation works were largely constructed prior to 1890. Its contention has been that the required major reservoir development to equalize the water supply will not result in any substantial increased depletion of Rio Grande flow at the State line; that in conjunction with drainage development it may, indeed, bring about an increase in that flow.

The major problem of the Middle and Elephant Butte-Fort Quitman sections is the maintenance of an adequate water supply for irrigation of the lands of the Middle Rio Grande Conservancy District in the Middle section and of the Rio Grande Project and Hudspeth County Conservation and Reclamation District in the Elephant Butte-Fort Quitman section. With respect to the latter section, there is the further problem of maintaining satisfactory control of salinity in the irrigated areas. Texas and New Mexico have vigorously resisted any major reservoir development in Colorado, on the ground that it would deplete the stream flow to an extent that would seriously jeopardize the water supply in New Mexico and Texas. Moreover, since the Middle Rio Grande Conservancy District began operations, Texas has contended that the use of water in the Middle district constitutes a menace to the water supply of the Rio Grande Project, which, it is asserted, will become more serious with complete development in the Middle district. In fact, on October 24, 1935, a suit was initiated in the United States Supreme Court by the State of Texas for the districts in the Rio Grande Project to enjoin the Middle Rio Grande Conservancy District and the State of New Mexico from alleged depletion of the water supply of the Rio Grande Project in violation of the Rio Grande compact.

The solution of these problems requires a comprehensive and adequate basis of fundamental facts—facts which definitely establish the available and potential water supplies, the present uses of water, and the requirements for it. With these facts in hand, reliable estimates should be possible of future changes in the water supply due to such developments as storage in Colorado, the proposed transmountain diversions from the basin of the San Juan, and the ultimate irrigation in the Middle Rio Grande conservancy district.

This report presents a basis of facts which it is hoped may prove adequate for the solution of these problems, to the end that the water resources of the Upper Rio Grande Basin may be put to maximum beneficial use and that all conflict of Federal, State, and local interests may be permanently dispelled.

Summary of Findings

Water Supply

Average annual precipitation in the Upper Rio Grande Basin ranges from less than 7 inches to 40 inches or more. The highest precipitation occurs in the Sangre de Cristo and San Juan ranges and the lowest in the central areas of the subvalleys of Rio Grande. With only 7 to 10 inches in these valleys, irrigation is essential for successful agriculture.

Mean annual lake-surface evaporation ranges from about 2 feet at an altitude of 9,500 feet on Rio Grande above San Luis Valley to about 6 feet at an altitude of 4,200 feet at Elephant Butte Reservoir.

Run-off in Rio Grande in the upper basin has been measured at five principal gaging stations for a period of 40 to 45 years. These stations are Del Norte and Lobatos, respectively above and below San Luis Valley, Otowi Bridge and San Marcial, respectively above and below the Middle valley, and El Paso. The mean annual run-off at these stations, together with the run-off of maximum and minimum years in percent of the mean, is shown in table 1.

TABLE 1.—[illegible]

Gaging station	Mean annual run-off, 1890–1935, acre-feet	[illegible] Maximum year	Minimum year
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
Otowi Bridge	[illegible]	[illegible]	[illegible]
[illegible][1]	[illegible]	221	[illegible]
[illegible][1]	[illegible]	[illegible]	[illegible]

[1] Regulated by Elephant Butte storage after 1915

Means of monthly run-off at the Del Norte and Otowi Bridge stations show that 70 percent of the annual run-off occurs between April and July, inclusive.

The total mean annual water production from run-off, 1890–1935, in the upper basin, is estimated at 3,060,000 acre-feet on the basis of all available stream-flow records. Of this total, 1,570,000 acre-feet originate in Colorado and 1,470,000 acre-feet in New Mexico. The production in the two States accounts for more than 99 percent of the total for the basin. Of the Colorado production, about 12 percent originates in the Closed Basin.

Depletion in San Luis Valley.—As shown by table 1, the mean annual run-off, 1890–1935, of Rio Grande at Lobatos was 550,000 acre-feet. Over a long period of years ending about 1927, there occurred a more or less steady increase in the depletion of stream flow to the southwest area in San Luis Valley; since 1927, there appears to have been little change in the depletion. Practically the entire flow of Rio Grande leaving San Luis Valley comes from the southwest area. Taking the average depletion, 1927–35, as representing present conditions in San Luis Valley, it is estimated that the mean annual flow under these conditions of Rio Grande at Lobatos, 1890–1935, would have been 448,000 acre-feet, or 102,000 acre-feet less than the mean of the recorded flow.

Middle Valley depletion.—Accurate determination of past stream-flow depletion in the Middle Valley is not possible because of the lack of adequate records of tributary inflow and uncertainty with respect to it. An approximation has been derived, based on such data as are available, in order to furnish a reasonable basis for analyses of the effect upon the Elephant Butte-Fort Quitman section of present and given future conditions of irrigation development in the San Luis and Middle sections. The mean annual stream-flow depletion, 1890–1935, Otowi Bridge to San Marcial, is estimated to have been 586,000 acre-feet. The corresponding mean annual tributary inflow derived as a residual in the method of estimating depletion is 359,000 acre-feet. Corrected for present development in San Luis Valley, the derived values for mean annual Middle Valley depletion and San Marcial flow are 580,000 and 1,030,000 acre-feet, respectively.

Return flow.—Return flow to Rio Grande in San Luis Valley has, in 3 years, 1934, 1935, and 1936, averaged 17 percent of the total Rio Grande diversions, or 36 percent of those diversions which contribute return flow to the river (excluding diversions to its closed basin). A return of 44 percent of diversions was indicated on the Conejos River by the data available for 1936. Return flow in the subdivisions of the Middle Rio Grande Conservancy District in the Middle Valley and the Rio Grande Project in the Elephant Butte-Fort Quitman section reaches the river above, and is available to, the next division downstream, except for return from the lowest divisions, Socorro in the Conservancy District and the Tornillo unit in Rio Grande Project. Return flow in the Conservancy District, as indicated by the total measured discharge of interior drains in 1936, was 28 percent of the gross diversions. Data were not available on net diversions. On the Rio Grande Project, return flow, represented by the total of measured drain flow averaged for the years 1930–36, was 50 percent of the average of total net diversions in the same period.

Ground water.—There has been little utilization of ground water as a basic source of supply for irrigation in the Upper Rio Grande Basin. The extensive control of ground water for the practice of subirrigation in certain San Luis Valley areas is, perhaps, an exception to this statement. The sources of recharge both to the shallow and artesian ground water basins of San Luis Valley are stream flow (chiefly as it crosses the alluvial fans bordering the valley), irrigation diversions, and precipitation on the valley floor. Depths to water in San Luis Valley, as shown by July 1936 measurements, were less than 5 feet over approximately 70 percent of the Closed Basin and over most of the Bowen-Carmel district and the general area east to the river. These ground water conditions, especially in the central and eastern portions of the Closed Basin, are favorable to the disposal of large quantities of ground water by evaporation and transpiration. A reconnaissance in 1936 of irrigation plants pumping from the shallow ground-water basin in San Luis Valley showed 176, and from discharges reported by owners or operators, the total output of all the plants operating continuously was estimated at 660 acre-feet per day. The number and total annual discharge of artesian wells in San Luis Valley were estimated from a 1936 inventory at 6,074 and 119,000 acre-feet, respectively. There is also an annual discharge from artesian springs of about 47,000 acre-feet.

The sources of ground water in the Middle Valley are underflow from the mesas on either side and seepage from the river, canals, and irrigated lands. In most areas, seepage from irrigated lands is the principal source, and the water in interior drains is largely derived therefrom. On the other hand, the river is, without doubt, the source of most of the water in the riverside drains. Meager data indicate a total annual underflow from the mesas of between 50,000 and 100,000 acre-feet. Depths to ground water in the Middle Rio Grande Conservancy District in 1936, compared to those in 1927 before drainage construction, show an average lowering of the water table over the entire district of 3 feet. October 1936 measurements showed depths to water of less than 3 feet in 4 percent of the

total valley area; depths of between 3 and 4 feet in 11 percent of the area; between 4 and 6 feet in 46 percent; between 6 and 8 feet in 28 percent; and more than 8 feet in 11 percent.

Average depths to ground water in Mesilla Valley of the Elephant Butte-Fort Quitman section, as shown by observations in January of each year, have been between 9 and 10 feet throughout the period 1925 to date.

Quality of water.—Investigation of the quality of water in the upper basin shows, in general, a progressive increase in salt concentrations in the downstream direction in streams, drains, and subsoil. On Rio Grande the data indicate a range in average concentration from 0.1 ton per acre-foot at Del Norte to 2.75 tons per acre-foot at Fort Quitman. The latter is equivalent to about 2,000 parts per million. In terms of electrical conductance ($K \times 10^5$ at 25° C.) the indicated average is 296. The average total quantity of salts carried annually ranges from 50,000 tons at Del Norte to 650,000 tons at Leasburg, at the head of Mesilla Valley on the Rio Grande Project. Below Leasburg the tonnage carried decreases to about 470,000 at Fort Quitman, indicating the annual loss of about 180,000 tons between those two stations. Changes in the downstream direction in composition of the constituent parts of the dissolved solids are to higher percentages of sodium and chloride and lower percentages of the other four major constituents—calcium, magnesium, bicarbonate, and sulphate. In terms of conductance the average salinity of irrigation water at El Paso and at Tornillo Heading, the lowest of the Rio Grande Project, is 127 and 212, respectively. Rough averages of the conductances of drain water, as indicated by the 1936 data, are 450 in the upper El Paso Valley and 500 or more in the lower, Tornillo unit. Control of salt in the soil solution of the root zone of plants and limitation to a noninjurious concentration by an increase in the amount of irrigation water applied is indicated for the lower unit of the Rio Grande Project.

Water Uses and Requirements

The use of water for irrigation constitutes practically the entire use in the upper basin. Use by cities, towns, and villages is relatively minor and that for water power negligible.

The complete survey in 1936 of irrigated and other water-consuming areas in the basin covered 2,093,000 acres. A segregation of the mapped areas, by water-use classification and basin section, is shown in table 2.

Based on the 1936 acreage data, on a review of studies of consumptive use and stream-flow depletion by previous investigators and on the results of research and field work in 1936, estimates have been prepared of the present consumptive requirements in the various subbasins of the upper basin. These estimates, summarized in table 3, take into account precipitation on the consumptive areas and indicate a total consumption in the basin, exclusive of tributary areas in the Middle and Elephant Butte-Fort Quitman sections, of 3,860,000 acre-feet. By including the tributary areas and reducing the estimates to give stream-flow depletion (by correcting for precipitation) a comparison of the results with the water production in the upper basin affords estimates of water surpluses or deficiencies as shown by table 4. For a year of normal water production there is an indicated basin surplus of 177,000 acre-feet. The average annual flow of Rio Grande at Fort Quitman for the 13-year period of record is 211,000 acre-feet. Similar comparisons show a basin surplus of more than a million and a half acre-feet in the maximum year and a deficiency slightly greater than this amount in the minimum year.

TABLE 2.—*Irrigated and other water consuming areas in the Upper Rio Grande Basin, 1936*

[illegible]

[illegible]	[illegible] other lands artificially given water			Other water consuming [illegible] nonirrigated			[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Bare lands, [illegible] rights-of-way, etc	
[illegible]							
[illegible]	[illegible]	[illegible]	1	[illegible]	4	37	[illegible]
Southwest area	[illegible]	7	1	[illegible]	7	18	[illegible]
[illegible]	[illegible]	3	1	157	3	[illegible]	231
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] New Mexico							
[illegible]	[illegible]			[illegible]			13
Middle Rio Grande conservancy [illegible]	[illegible]			[illegible]	[illegible]		188
Middle Rio Grande conservancy [illegible]	[illegible]			[illegible]	[illegible]		17
[illegible]	[illegible]		[illegible]	[illegible]			
[illegible]	[illegible]		[illegible]	[illegible]	39	11	568
[illegible]							
[illegible]			[illegible]	[illegible]		[illegible]	137
[illegible]	[illegible]			30	8	[illegible]	210
[illegible]	[illegible]	[illegible]					[illegible]
[illegible]				4	3		[illegible]
[illegible]	[illegible]	11	[illegible]	[illegible]	16	[illegible]	[illegible]
Upper Rio Grande Basin	[illegible]	16	19	918	[illegible]	[illegible]	[illegible]

[illegible]

TABLE 3.—*Estimates of consumptive water requirements in Upper Rio Grande Basin*[1]

Item	San Luis section	Main stem of Rio Grande in Middle section	Main stem of Rio Grande in Elephant Butte-Fort Quitman section
Irrigated lands:			
Area in 1,000 acre units	600	[illegible]	[illegible]
Consumption in 1,000 acre-feet units	1,043	172	[illegible]
Acre-feet per acre	1.7	[illegible]	2.8
Native vegetation:			
Area in 1,000 acre units	[illegible]	107	66
Consumption in 1,000 acre-feet units	1,056	[illegible]	[illegible]
Acre-feet per acre	1.4	3.6	4.0
Miscellaneous:[2]			
Area in 1,000 acre units	[illegible]	[illegible]	[illegible]
Consumption in 1,000 acre-feet units	135	147	[illegible]
Acre-feet per acre	1.2	3.3	3.7
Totals:			
Area in 1,000 acre units	[illegible]	218	286
Consumption in 1,000 acre-feet units	2,234	706	[illegible]
Acre-feet per acre	1.5	3.2	3.2

[1] Includes consumption of precipitation.
[2] Cities, towns, and villages, lands temporarily out of cropping, water surfaces and exposed beds; bare land, roads, rights-of-way, etc.
[3] Excludes area of city of El Paso.

TABLE 4.—*Water supply and stream-flow depletion in Upper Rio Grande Basin for a normal year and present use of water*

Item	San Luis section	Middle section	Elephant Butte-Fort Quitman section	Upper Rio Grande Basin
Irrigated and water-consuming acreage, 1936	[1] 1,047,000	367,000	336,000	1,750,000
Stream-flow depletion in acre-feet	[2] 1,047,000	768,000	885,000	2,700,000
Water production—total natural run-off in acre-feet	[3] 1,379,000	1,333,000	165,000	2,877,000
Surplus or deficiency	332,000	565,000	−720,000	177,000

[1] Excludes closed basin area except that irrigated from Rio Grande.
[2] Excludes closed basin consumption except by area served from Rio Grande.
[3] Excludes water production of closed basin.

Diversion requirements.—Based on all available relevant data and on studies of consumptive use, stream-flow depletion, return flow, wastes, salinity, and present irrigated and other water-consuming acreages, estimates of the diversion requirements, or demands upon the stream flow of the major units of the upper basin have been developed as shown in table 5. These are the demands for full development as represented by the irrigated areas shown. The estimates of stream-flow depletion in each unit, from which the demands were derived, are indicated. The demand for the Rio Grande Project and for fulfillment of the Mexican treaty obligation includes a 60-percent increase in the diversion requirement for the Tornillo unit of Rio Grande Project. This is an estimated allowance for salinity control. It is experimental and may be modified as experience dictates.

The total annual stream-flow depletion by cities, towns, and villages in the upper basin, excluding El Paso, is estimated to be 21,000 acre-feet. The annual draft on deep wells supplying the municipal and industrial requirements of El Paso is about 14,000 acre-feet.

Storage, Importation, and Salvage of Water.

The present storage capacity of reservoirs in the upper basin is 2,872,000 acre-feet. Of this, 309,000 acre-feet is in Colorado and 2,563,000 acre-feet in New Mexico. Of the Colorado storage, 131,000 acre-feet capacity is in the upper Rio Grande drainage above San Luis Valley. Some 2,274,000 acre-feet or 89 percent of the New Mexico storage capacity is accounted for by Elephant Butte Reservoir.

TABLE 5.—*Estimated diversion demands upon stream flow, major units of Upper Rio Grande Basin*

Basin unit	Demand upon stream flow acre-feet	Source and required location of supply	Irrigated acreage for full development, maximum in any one year	Estimated stream-flow depletion upon which demand is based, acre-feet
Rio Grande area of San Luis Valley.	650,000	Rio Grande at Del Norte gage.	350,000	455,000
Conejos area of San Luis Valley.	230,000	Conejos River at Mogote gage and San Antonio River at mouth.	80,000	150,000
Middle Valley, Otowi Bridge to San Marcial				550,000
Middle Rio Grande Conservancy District.	580,000	Rio Grande at Otowi Bridge and divertible tributary inflow below.[1]	100,000	
Conservancy district to San Marcial.[2]	80,000	Rio Grande at San Antonio and tributary inflow below.	1,000	
Rio Grande project and Mexican area.[3]	953,000	Rio Grande at San Marcial.		[4] 180,000
	773,000	Elephant Butte Reservoir.	[5] [illegible]	[5] 441,000

[1] Tributary inflow from Cochiti to San Felipe plus a portion of Jemez flow. Mean annual usable inflow estimated at about 110,000 acre-feet, or 31 percent of total tributary inflow to Middle Valley.
[2] This area is largely native vegetation, swamp, and overflow lands.
[3] Hudspeth district not included as its water supply is derived from and entirely dependent upon residual flow drainage return, and waste from Rio Grande Project.
[4] Estimated reservoir evaporation and seepage.
[5] For Rio Grande project only.

Storage projects that have been proposed for the basin and data resulting from their investigations in 1936–37 are listed in table 6. Although primarily for irrigation, incidental benefit in the control of floods is indicated for the larger reservoirs.

Possible sources of additional water supplies for the upper basin are importations from the San Juan drainage of the Colorado River Basin and salvage of present wastes and losses. Data developed by the Rio Grande Joint Investigation with respect to possible transmountain diversions from the upper San Juan Basin are summarized in table 7. Existing developments in the San Juan Basin as far down as Shiprock

would not be impaired by any of these diversions. In the event of more extensive future development of San Juan areas than now anticipated, some compensating storage on San Juan River or a tributary may be required.

Of the upper basin water consumption shown by table 3, 44 percent is accounted for by the irrigated areas and 44 percent by the areas of native vegetation. In other words, there is a nonbeneficial consumption of water by native vegetation equal in amount to the consumption by the irrigated lands. Reduced to terms of stream-flow depletion, native vegetation takes an average annual toll from the basin of more than 1,000,000 acre-feet of water. The data are not developed to determine what portion of this amount might be economically recovered, principally by proper drainage construction, but it is undoubtedly a fraction which would signify a substantial saving of water. There is still a great amount of undrained land in the basin. The estimated mean annual yield of the sump drain, a trunk drain proposed to collect the waters in the sump area of the Closed Basin, San Luis Valley, and discharge them to Rio Grande, is about 40,000 acre-feet. Chemical analyses of tributary stream flow, drainage, and ground water of the sump area indicate that the salt concentration of the sump-drain water might be as much as 1.5 tons per acre-foot initially, with a possible reduction, in time, to 1 ton or less, per acre-foot.

Availability and Use of Water under Given Conditions

Using the data developed by this investigation with respect to water supply, its uses and requirements, and opportunities for its storage, importation, and salvage, analyses were made to determine the effect upon, and conditions of water supply and use in, the San Luis, Middle, and Elephant Butte-Fort Quitman sections, under 11 different given combinations or conditions of storage development and draft. The salient features of the various conditions are outlined in table 8, which gives a summary of the analyses by showing for each

TABLE 6.—*Storage projects under investigation, 1936-37, Upper Rio Grande Basin*

Project	State	Stream	Type of dam	Reservoir capacity	Estimated mean annual run-off to reservoir	Estimated cost,[1] dollars: Total	Estimated cost,[1] dollars: Per acre-foot of capacity
				Acre-feet	*Acre-feet*		
[illegible]	Colorado	Rio Grande	Concrete arch	1,000,000	473,000	[illegible]	[illegible]
[illegible]	do	do	Earth and rock	240,000	344,000	4,826,000	20.10
[illegible]	do	Conejos	do	100,000	[illegible]	3,700,000	37.00
[illegible]	do	do	do	100,000	256,000	{3,655,000 {2,601,000	[illegible] 5.75
[illegible]	do	do	Compacted embankment	32,000	49,000	[illegible]	[illegible]
[illegible]	do	[illegible]	do	30,000		746,000	[illegible]
[illegible]	New Mexico [illegible]	Rio Grande	[illegible]	452,00			

[1] Exclusive of railroad relocation and power installation.
[2] Data are tentative.

TABLE 7.—*Transmount[illegible] projects, Upper San Juan Basin to Upper Rio Grande Basin*

[illegible]	State	Local drainage: [illegible]	Local drainage: To—	Reservoirs: Stream or name	Reservoirs: [illegible]	Conduit system, length in miles: Tunnel	Conduit system, length in miles: [illegible]	Conduit system, length in miles: Total	Estimated mean annual yield	Estimated cost: Total	Estimated cost: Per acre-foot of diversion
					[illegible]				*Acre-feet*		
[illegible]	[illegible] Mexico.	East and west forks San Juan, Turkey, Blanco, Navajo.	[illegible]	West fork, San Juan	70,000	[illegible]	78.3	[illegible]	350,000	[illegible] $20,000,000	$57
				East fork, San Juan	[illegible]						
				Blanco	15,000						
				[illegible]	50,000						
[illegible]	[illegible]	[illegible] Mineral, Mineral, Cement.	Headwaters Rio Grande.	[illegible] Animas.	[illegible]	[illegible]	11.1	26.6	[illegible] 131,000	10,432,000	[illegible]
[illegible]	[illegible]	Pine	[illegible]				[illegible]	7.5	[illegible]	264,000	[illegible]
[illegible]		West fork San Juan, [illegible]	South fork Rio Grande.			[illegible]	[illegible]	13.5	[illegible] 53,000	5,290,000	100

[illegible]

condition: (1) the mean annual run-off of Rio Grande at Lobatos and San Marcial, (2) the minimum and mean August run-off at Lobatos, and (3) the maximum shortages in San Luis, Middle, and Elephant Butte-Fort Quitman sections, for two periods, 1892–1904 and 1911–35.

Consideration of the data of mean annual run-off of the Rio Grande near Lobatos under the various conditions indicates that the effect of increased storage development in the San Luis Valley is to decrease the annual run-off in high water years by storage and to increase it during low years by release of water held over from the more abundant years. Except for Conditions Nos. 5 and 10, the latter representing greatest possible development in San Luis Valley, the mean annual flow at Lobatos under the various conditions indicated remains practically unchanged from that of the present (Condition No. 2).

Study of the monthly flow at Lobatos under the various conditions indicates an improvement in nearly every case over present conditions, in the regimen of flow from month to month, particularly in the summer and fall months of low-water years. In these months the flow is built up by the improved and redistributed return flow resulting from diversions which storage regulation has permitted to be made more in keeping with the irrigation demand.

Severe shortages are indicated in all three sections of the upper basin in the early critical period 1899–1904 under every condition for which an analysis covering this period was made, with the exception that in the Middle Valley, under Condition No. 11, there was no shortage. Under Conditions Nos. 4 and 5 which include Wagon Wheel Gap Reservoir with return flow to the Rio Grande in San Luis Valley taken at 16 and 8 percent, respectively, of the total Rio Grande diversions in the valley, shortages in the Middle Valley are substantially reduced from those indicated for present conditions, except under Condition No. 5 in the early period for which the shortage remains the same.

In Elephant Butte-Fort Quitman section under Conditions Nos. 4 and 5 the shortages in the early period are increased over those under present conditions. No shortages, however, occur in the 1911–35 period and the minimum content of Elephant Butte Reservoir in this period under Condition No. 5 would have been 364,000 acre-feet.

From a study of the amounts and occurrences of the

TABLE 8.—*Mean annual run-off of Rio Grande at Lobatos and San Marcial, minimum and mean August run-off at Lobatos, and maximum shortages in San Luis, Middle, and Elephant Butte-Fort Quitman sections, 1892–1904 and 1911–35, under various given conditions of storage and irrigation draft*

[Unit 1,000 acre-feet]

Item	Condition number[1]										
	1	2	3	4	5	6	7	8	9	10	11
Mean annual run-off at Lobatos:											
1892–1904		308		320	275						315
1911–35	588	478	490	485	433		486			547	472
Mean annual run-off at San Marcial:											
1892–1904		769		766	732						693
1911–35		1,082		1,085	1,038		1,084			946	1,014
Minimum August run-off at Lobatos:											
1902		.6		1.1	.3						5.9
1934	1.7	1.2	1.5	15.3	6.5		24.5			2.7	12.1
Mean August run-off at Lobatos:											
1892–1904		4.0		14.0	8.0						13.6
1911–35	18.2	15.5	24.1	25.4	16.6		34.9			33.0	22.2
Maximum shortage:											
San Luis section:											
1892–1904				425							
1911–35	424		357	0		36		141	151		
Middle section:											
1892–1904		191		162	192						0
1911–35		237		161	225		80			119	0
Elephant Butte-Fort Quitman section:											
1892–1904		383		451	480						538
1911–35		0			0					0	0
Minimum storage in Elephant Butte Reservoir:											
1892–1904		0		0	0						0
1911–35		700		665	364					88	[illegible]

[1] Conditions:
No. 1. No increased storage in S.; A. for R.
No. 2. Present conditions in S.; A. for M. and E.
No. 3. V. S.; A. for R.; R. R. F. = 16 percent.
No. 4. W.; A. for R. and M.; R. R. F. = 16 percent.
No. 5. W.; A. for R., M., and E.; R. R. F. = 8 percent.
No. 6. Con.; A. for C.; C. R. F. = 35 percent.
No. 7. W. and Con.; A. for R., C., and M.; R. R. F. = 16; C. R. F. = 35.
No. 8. W. and V. S.; Max. for R.; total return same as given by no. 4.
No. 9. Con.; Max. for C.; total return same as given by no. 6.
No. 10. W., V. S., and Con.; Max. for R. and C.; A. for M. and E.; total return in S. same as given by nos. 4 and 6.
No. 11. W., S. L., and S. D.; A. for R., M., and E.; R. R. F. = 8.

Key to Symbols Used in List of Conditions

A. = Adopted diversion demand, i. e., 650,000 acre-feet for R, 230,000 for C., 580,000 for M., and 773,000 for E.
C. = Conejos area.
Con. = Conejos Reservoirs.
C. R. F. = Return flow to Conejos in percent of Conejos diversions.
E. = Elephant Butte-Fort Quitman section.
M. = Middle section.
Max. = Diversion demand for maximum development, i. e., 750,000 acre-feet for R. and 300,000 for C.
R. = Area served from Rio Grande in San Luis Valley.
R. R. F. = Return flow to Rio Grande in San Luis Valley in percent of total Rio Grande diversions in the valley.
S. = San Luis section.
S. D. = Sump drain.
S. L. = State Line Reservoir.
V. S. = Vega-Sylvestre Reservoir.
W. = Wagon Wheel Gap Reservoir.

shortages in the three sections of the basin under the various conditions, it is indicated that the transmountain diversions would be beneficial principally in relieving the shortages of critical periods and years, such as 1899–1904 and 1934, although by the same token that there were severe shortages in these years in the Rio Grande Basin, the San Juan supply and hence the diversions would probably have been correspondingly short.

There would be opportunity for use of the imported water for development of new lands during the period of a generation or more when no shortages are indicated under any of the conditions except Nos. 1 and 9, but the new lands would of necessity suffer severe shortages in the years when the transmountain diversions would be needed to alleviate shortages in the present developed areas.

PART I
SECTION 2.—WATER SUPPLY

Description of Basin

The Upper Rio Grande Basin occupies a portion of southern Colorado, a strip through central New Mexico from north to south, and a small portion of western Texas and northern Mexico. The total length of Rio Grande above Fort Quitman, Tex., the lower extremity of the upper basin, is about 650 miles and the tributary drainage area, excluding the closed basin in San Luis Valley, Colo., is 31,000 square miles. For the purposes of this study and more or less in conformity with natural divisions, the basin is segregated into three areas designated as the San Luis section in Colorado, the Middle section in New Mexico, and the Elephant Butte-Fort Quitman section in New Mexico, Texas, and Mexico. These are indicated on the map, plate 1.

The San Luis Section

The San Luis Valley is a plain approximately 90 miles from north to south and 50 miles from east to west. The altitude of the valley floor ranges from 7,440 feet on the south, where Rio Grande passes between the San Luis Hills to about 8,000 feet around its rim. The surrounding mountains attain altitudes generally above 10,000 feet, while Mount Blanca on the east rises to 14,390 feet. The valley is bounded on the west by the Conejos Mountains and La Garita Hills, on the north by the Saguache and Sangre de Cristo Mountains, on the east by the Sangre de Cristo Mountains, and on the south by the San Luis Hills. The Continental Divide is to the west, consisting of the San Juan Mountains and the Cochetopa Hills. The water-producing area comprises the mountainous regions above the 8,000-foot contour defining the rim of the valley. Rio Grande rises in the San Juan Mountains near the Continental Divide and, flowing in a southeasterly direction between the Conejos Mountains and La Garita Hills, enters the valley proper on the west at Del Norte. It continues southeasterly through Monte Vista to Alamosa, at which point it takes a southerly course for nearly 40 miles and, passing through a break in the San Luis Hills, enters New Mexico.

With respect to water supply, San Luis Valley may be conveniently divided into three sections: The closed basin, the southwest area, and the southeast area. A low divide has been formed across the valley by the alluvial fan of Rio Grande on the west and the alluvial material from the Sangre de Cristo Mountains on the east. This divide, almost imperceptible to the eye, extends southeasterly from the vicinity of Del Norte to a point a few miles north of Alamosa and thence easterly to the eastern rim of the Valley. To the north of this divide there is a valley area of 2,940 square miles which is not tributary to Rio Grande. This is termed the Closed Basin. The lowest portion or "sump" of this basin is located close to the foot of the Sangre de Cristo Mountains on the east side of the valley, and is plainly defined by a chain of lakes of which San Luis Lake is the largest, and by a succession of alkali flats extending from Washington Springs near the Denver & Rio Grande Western R.R. on the south to a point on the north some 5 miles northeast of Gibson. The streams entering the valley in the closed basin are La Garita and Carnero from the west, Saguache from the northwest, Kerber and San Luis from the north, and Cotton, Wild Cherry, Rito Alto, North and South Crestone, Willow, Spanish, Cottonwood, Deadman, Sand, Medano, and Zapato from the east. Practically all water produced by these streams that is not consumed in irrigation flows to the sump and is lost by evaporation. In addition, all water diverted from Rio Grande for a large acreage in the closed basin, and not consumed in irrigation there, is lost in the sump area.

The southwest area of San Luis Valley lies south of the closed basin, west of Rio Grande and north of the New Mexico State line. Conejos River, the principal tributary of Rio Grande in Colorado, rises in the mountains to the southwest, enters the valley at its southwest corner and flows northeasterly to join Rio Grande

[illegible]

north of La Sauses. Los Pinos and San Antonio Rivers are tributary to the Conejos from the southwest. Los Pinos River joins the San Antonio near Ortiz and the latter joins the Conejos in the valley near Manassa. Tributaries from the west between the Conejos and Rio Grande are La Jara, Alamosa, and Rock Creeks.

The southeast area extends east from Rio Grande to the lower slope of the Culebra Range of the Sangre de Cristo Mountains and, as here considered, from the New Mexico State line north to the south slope of Mount Blanca and to the closed basin. The streams entering this area flow from the east and are, from north to south, Trinchera Creek, Culebra Creek, and Costilla River. Sangre de Cristo and Ute Creeks are tributaries of the Trinchera. Costilla River rises in New Mexico, flows north and west for about 10 miles in Colorado and then turns south and joins the Rio Grande in New Mexico. These streams contribute very little to the Rio Grande as their waters are largely regulated and absorbed by irrigation before they reach the river.

The Middle Section

The Middle section is taken to include the Rio Grande and tributary valleys from the Colorado-New Mexico State line to San Marcial at the head of Elephant Butte Reservoir, a river distance of about 270 miles. The upper half of this stretch of Rio Grande is flanked on the east by the southern extension of the Sangre de Cristo Mountains, which maintain their high altitudes as far south as the Glorietta Divide east of Santa Fe. On the west, the Conejos Range extends southward between the river and its principal New Mexico tributary, Rio Chama, succeeded south of the latter by the Jemez Mountains. It is from this portion of the drainage area that Rio Grande receives most of the part of its water supply which originates in New Mexico. South of Santa Fe on the east and Jemez Mountains on the west, the flanking ranges decrease in height. There is also a marked change in the character of the precipitation; heavy winter snows on the higher northern mountains give place to sporadic and sometimes violent downpours, most of them in summer, on the lower southern ranges. Tributary streams south of Rio Chama are therefore largely torrential in character and productive of a relatively small total run-off to Rio Grande.

A few miles north of the Colorado-New Mexico State line, Rio Grande enters a canyon which gradually increases in depth to more than 1,200 feet at Embudo,

[illegible]

70 miles south of the line. In this stretch, the tributaries are from the east and include Rio Colorado, Rio Hondo, Rio Taos, and Embudo Creek. These streams rise in the Sangre de Cristo Mountains and afford water for irrigation on the mesa lands at the foot of the mountains. There is some residual flow to Rio Grande.

A short distance below Embudo the river enters Espanola Valley, which is some 25 miles long and from 1 to 3 miles wide. Here it is joined by Rio Chama from the west and Rio Santa Cruz from the east. The Chama is an important stream draining some 3,200 square miles and on it, about 60 miles above its mouth, is situate the El Vado Reservoir of the Middle Rio Grande Conservancy District. There is some irrigation development in its mountain valleys. On Rio Santa Cruz there is a small reservoir and the lands in its valley are irrigated.

At the lower end of Espanola Valley, the river enters White Rock Canyon, a narrow tortuous gorge some 20 miles long, and, leaving this at a point almost due west of Santa Fe, it enters a long narrow valley bounded on each side by mesas which rise abruptly to a height of 300 to 500 feet above the valley floor and then slope gently upward to the foot of the mountains. This is the principal valley of the Middle section and it extends 150 miles to San Marcial Narrows, broken only by short canyons or narrows at San Felipe, Isleta, and San Acacia which define the subvalleys of Santo Domingo, Albuquerque, Belen, and Socorro. These valleys vary in width from 1 to 4 or 5 miles. Albuquerque, the largest city of New Mexico, is in Albuquerque Valley, 45 miles below White Rock Canyon. The Middle Rio Grande Conservancy District includes the valley lands from White Rock Canyon to the southern third of Socorro Valley. The principal tributaries are Santa Fe and Galisteo creeks, entering Santo Domingo Valley from the east, Jemez Creek from the west, a few miles below San Felipe Narrows, and Rio Puerco and Rio Salado from the west just above San Acacia Narrows, 65 miles south of Albuquerque. These streams are largely torrential in character and only contribute discharge of consequence to Rio Grande at times of flashy floods. Rio Puerco drains some 5,000 square miles, but this is an area of relatively low altitude and scant precipitation, although subject to irregular and sudden storms of cloudburst proportions. There is some irrigation along Rio Puerco and its tributaries and in Jemez Creek Valleys.

The Elephant Butte-Fort Quitman Section

The Elephant Butte-Fort Quitman section comprises the Rio Grande Valleys from San Marcial to Fort Quitman, Tex., a distance of 250 miles. For 65

[illegible] Percha Dam, Rio Grande Project—Head of Rincon Valley, N. Mex.


PRECIPITATION STATIONS IN THE UPPER RIO GRANDE BASIN
NO.
STATION
COUNTY
STATE
SAN LUIS SECTION
MIDDLE SECTION
ELEPHANT BUTTE-FORT QUITMAN SECTION

PLATE 2

miles from San Marcial to Caballo Narrows the flanking hills are close to the river and there is little valley land. The Elephant Butte Reservoir occupies the first 40 miles of this stretch and below it is the small Palomas Valley.

From Caballo Narrows the river enters the Rincon Valley, which is about 30 miles long and has maximum widths of about 2 miles. This terminates in Selden Canyon, at the lower end of which the hills flatten out and recede from the river to form the beginning of Mesilla Valley. This is one of the larger subvalleys. It extends 55 miles south to "The Pass", 4 miles above El Paso, and has a maximum width of about 6 miles opposite Las Cruces, 45 miles north of El Paso.

Below El Paso, Rio Grande is the boundary between Texas and Mexico. On the west side the boundary between New Mexico and Mexico is at "The Pass", but on the east side the New Mexico-Texas line is about 20 miles north of El Paso. The El Paso Valley, which is the lowest in the Upper Rio Grande Basin, is about 90 miles in length from El Paso to the gorge in an extension of the Quitman mountains about 10 miles below Fort Quitman. Widths vary from 4 to 6 miles for much of its length. On the Texas side it includes the lands of the El Paso County Water Improvement District and the Hudspeth County Conservation and Reclamation District. The area on the Mexican side is generally referred to as Juarez Valley. The Rio Grande Project of the Bureau of Reclamation includes the valley lands from Caballo Narrows to El Paso and to a point about 40 miles below the latter, on the Texas side.

Tributaries in the Elephant Butte-Fort Quitman section consist only of arroyos, dry most of the time but subject to flashy floods. The principal ones enter from the west between San Marcial and Rincon Valley and are, in downstream order, Milligan Gulch, San Juan, Nogal, San Jose, Rio Canada Alamosa, Cuchillo, Palomas, Arroyo Seco, Las Animas, Percha, Tierra Blanca, and Jaralosa. The first five are tributary to Elephant Butte Reservoir and the next four are tributary above the dam of Caballo Reservoir now under construction. A channel is being built to divert the flow of the Percha to this reservoir.

Climatological and Related Data

Table 9 gives the altitudes of the valley areas of the Upper Rio Grande Basin.

Temperatures

The mean annual and July and January temperatures and the periods between killing frosts, or the growing seasons, are given in table 10 for representative locations in the three major valley areas of the upper basin. These are taken from the Climatological Summaries to 1930 of the United States Weather Bureau.

TABLE 9.—*Altitudes of valley areas in the Upper Rio Grande Basin*

Area or location	Altitudes
San Luis section—Valley floor	From [illegible] to [illegible]
Del Norte	7,880
Monte Vista	[illegible]
Alamosa	7,550
"Sump" in closed basin	[illegible]
Rio Grande at valley outlet	[illegible]
Middle section—valley floor	From [illegible] to [illegible]
Espanola Valley	[illegible]
Santo Domingo Valley	[illegible]
Albuquerque Valley	[illegible]
Albuquerque	5,000
Belen Valley	4,900
Socorro Valley	[illegible]
San Marcial	4,450
Elephant Butte-Fort Quitman section	From 4,250 to 3,400
Palomas Valley	4,200
Rincon Valley	4,150
Mesilla Valley	4,000
Las Cruces	[illegible]
El Paso Valley	3,600
El Paso	3,710
Fort Quitman	3,400

TABLE 10.—*Mean annual, July, and January temperatures and length of growing season in the Upper Rio Grande Basin*

Station	Temperatures in degrees Fahrenheit									Average length of growing season, number of days from killing frost in spring to killing frost in fall
	Annual			July			January			
	Average			Average			Average			
	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	
San Luis section:										
Del Norte	57.7	26.9	42.3	76.4	46.9	61.6	36.6	5.6	21.1	121
Garnett	59.2	23.0	41.1	80.3	44.7	62.5	35.3	−1.1	17.1	97
Manassa	58.3	25.1	41.7	78.6	46.7	62.6	36.6	3.0	19.8	99
Middle section:										
Bernalillo	70.7	39.6	55.2	90.9	61.2	76.0	48.4	21.3	34.8	
Albuquerque	69.2	41.9	55.6	89.7	62.6	76.2	47.2	22.2	35.0	[illegible]
Socorro	74.1	40.7	57.4	92.5	61.8	77.2	52.8	22.6	37.7	195
San Marcial	75.2	41.3	58.2	93.9	62.4	78.2	53.9	22.5	38.2	[illegible]
Elephant Butte-Fort Quitman section:										
Elephant Butte	73.8	45.3	59.6	91.6	65.8	78.7	54.3	26.9	40.6	221
Agricultural College	76.2	44.0	60.1	93.4	65.1	79.2	58.1	25.8	[illegible]	[illegible]
El Paso	76.1	50.8	63.6	92.8	69.3	81.6	57.6	[illegible]	44.9	241
Clint	78.0	42.1	60.1	94.4	61.8	78.1	59.0	22.5	40.7	201
Fort Hancock	80.7	38.4	60.2	98.8	61.3	81.2	60.1	19.1	39.7	

Precipitation

The longest record of precipitation in the Upper Rio Grande Basin is for Santa Fe. It begins with 1850 and is continuous to date. Other stations with notably long records of complete years are San Marcial, 80 years; New Mexico State Agricultural College, 79 years; El Paso, 68 years; Albuquerque, 66 years; and Elephant Butte, 52 years. In the Middle Valley drainage there are six stations with records of between 40 and 50 years. The longest record in San Luis Valley is that of 46 years for Garnett, a few miles northwest of Alamosa.

Plate 2 gives a list of the precipitation stations in or near the Upper Rio Grande Basin. It also shows in each case the station elevation, its county and State, and the number and period of years of the record as

published by the Weather Bureau. The stations are grouped to the three major areas—San Luis, Middle, and Elephant Butte-Fort Quitman sections—and are numbered consecutively from north to south. The locations of these stations are shown on plate 3, "Distribution of precipitation in the Upper Rio Grande Basin," on which is given also the list of stations and numbered designations as indicated at each dot representing a station.

The records of annual precipitation for all stations listed are given in table 117 in Appendix A for all complete years from the initiation of the record to 1935, inclusive. Given also, for each station is the mean annual precipitation for the period of record. The length of the records is so variable that the means for the periods of record do not furnish an appropriate basis for comparison. For the latter the precipitation should be referred to the same period of years for all stations. Based on actual records this would necessitate selection of a period of less than 10 years, since the record for many stations is no longer than that. Obviously this would be undesirable, however, as no account would be taken of the several long-time records to derive means for a much longer and more representative period. The expedient adopted under these circumstances was to select, for the comparison, the 46-year period 1890–1935, inclusive, and in the case of stations having shorter records to estimate the mean by comparison with the precipitation at those nearest stations for which there is an actual record for the 46 years. It is recognized that, due to the marked irregularity in the distribution of precipitation throughout the basin, the figures thus derived are subject to some error. It is believed, however, that they furnish a much better and more truly representative basis for showing the amount and distribution of precipitation than the means based upon the period of record only.

The period 1890–1935 corresponds to that for which estimates of run-off are derived as considered elsewhere in this section of the report. Although precipitation records do not, in general, furnish the appropriate basis for estimates of run-off in the Upper Rio Grande Basin that they do in some other western basins, it is of value to have the precipitation data for a period corresponding to that for which run-off estimates are derived, if only to indicate the general relation which exists.

The estimated 46-year precipitation means are given in table 117, Appendix A, and are indicated at the station locations on plate 3. With these data as a basis, isohyetals or lines of equal precipitation were drawn to differentiate and indicate the variation in mean annual precipitation over the various basin areas. On this map each shade of color bounded by the isohyetals represents an area having mean annual precipitation within the limits indicated in the legend.

It will be noted that there is a range in mean annual precipitation from less than 7 inches to as much as 40 inches. The higher figures are for the high mountain areas of the Sangre de Cristo and the San Juan ranges in Colorado and northern New Mexico, and the lowest for the central areas of the main valleys. The aridity of the latter, as shown by the mean annual precipitation of from 7 to 10 inches only, well explains the requirement for irrigation in the San Luis, Middle, and Elephant Butte-Fort Quitman sections.

To indicate the monthly distribution of precipitation, figure 4 gives the average monthly precipitation in inches and in percent of the annual for three stations—Garnett, Albuquerque, and El Paso—as representative of the main valley areas, and for Cumbres, as representative of the high mountain areas. It will be noted that in the valley areas the months of greatest precipitation are July, August, and September, and that those months account for about half of the annual precipitation. On the other hand, in the high mountain areas, the greatest precipitation, mostly in the form of snow and the chief source of run-off, occurs in December, January, February, and March, and also represents roughly half of the annual precipitation.

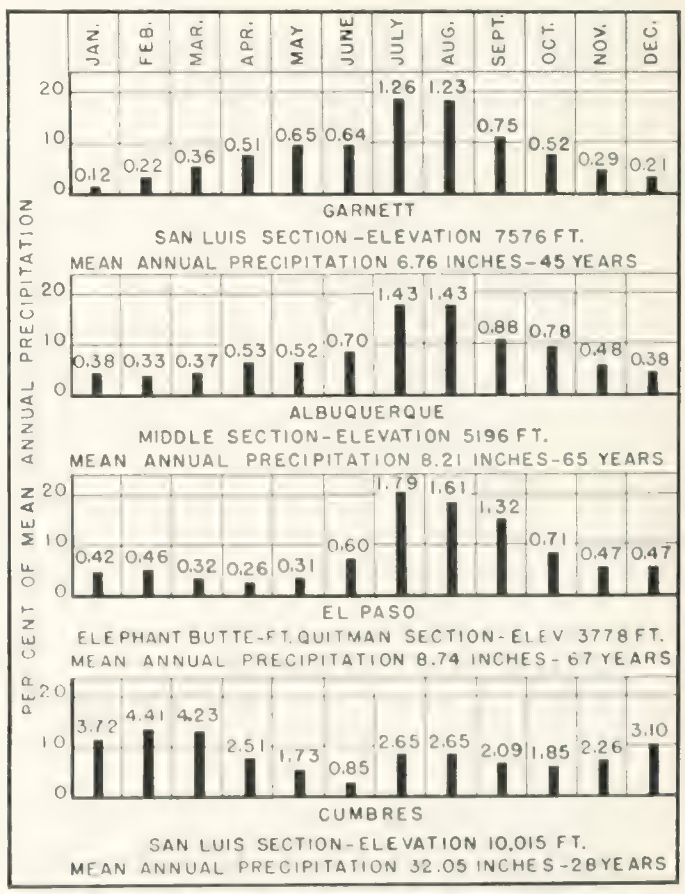
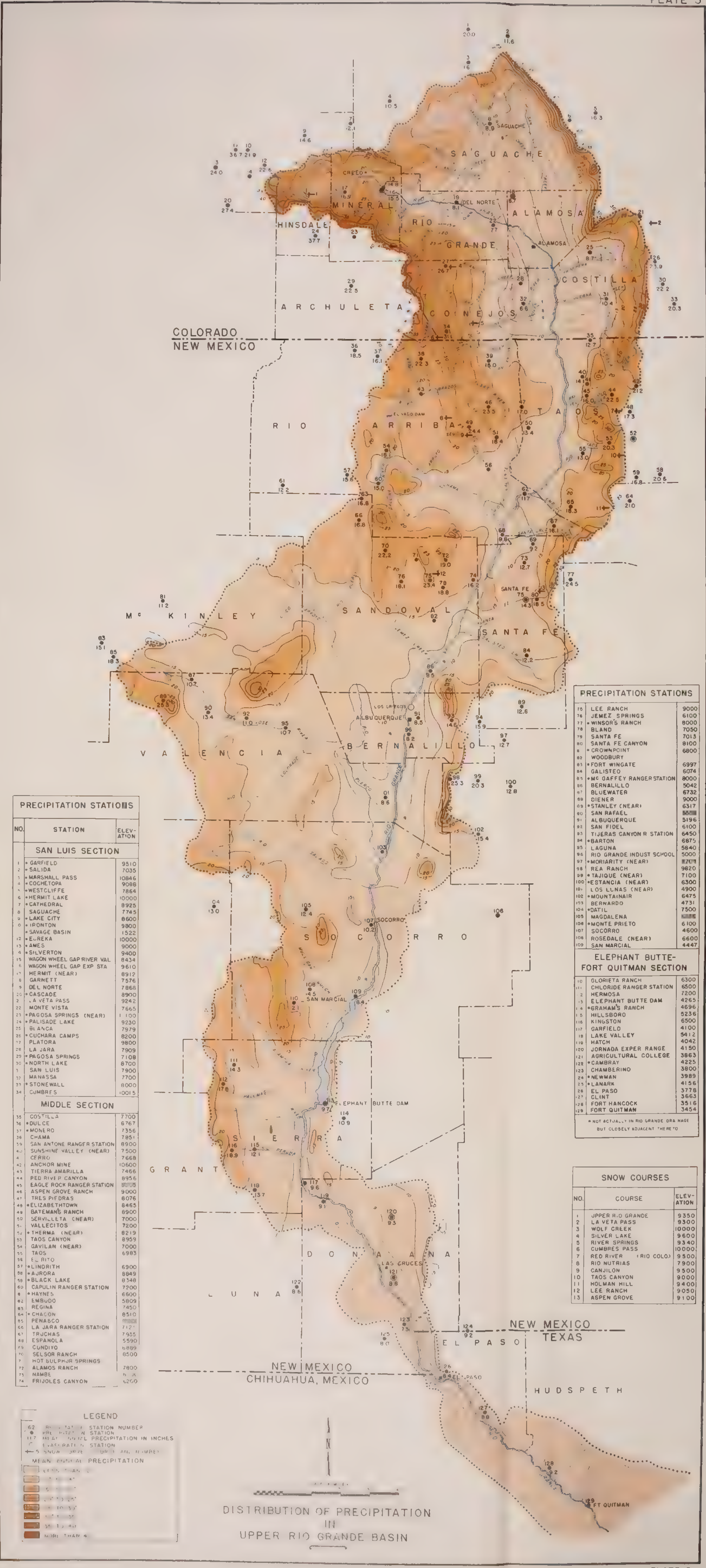


FIGURE 4.—Monthly distribution of precipitation in the Upper Rio Grande Basin
[illegible]



DISTRIBUTION OF PRECIPITATION
IN
UPPER RIO GRANDE BASIN

PRECIPITATION STATIONS

NO.	STATION	ELEVATION
	SAN LUIS SECTION	
1	• GARFIELD	9510
2	• SALIDA	7035
3	• MARSHALL PASS	10846
4	• COCHETOPA	9088
5	• WESTCLIFFE	7864
6	• HERMIT LAKE	10000
7	• CATHEDRAL	8925
8	SAGUACHE	7745
9	• LAKE CITY	8600
10	• IRONTON	9800
11	• SAVAGE BASIN	1522
12	• EUREKA	10000
13	• AMES	9000
14	• SILVERTON	9400
15	WAGON WHEEL GAP RIVER VAL	8434
16	WAGON WHEEL GAP EXP STA	9610
17	HERMIT (NEAR)	8912
18	GARNETT	7576
19	DEL NORTE	7868
20	• CASCADE	8900
21	LA VETA PASS	9242
22	MONTE VISTA	7665
23	• PAGOSA SPRINGS (NEAR)	1 100
24	• PALISADE LAKE	9230
25	BLANCA	7979
26	• CUCHARA CAMPS	8200
27	PLATORA	9800
28	LA JARA	7909
29	• PAGOSA SPRINGS	7108
30	• NORTH LAKE	8700
31	SAN LUIS	7900
32	MANASSA	7700
33	• STONEWALL	8000
34	CUMBRES	10015
	MIDDLE SECTION	
35	COSTILLA	7700
36	• DULCE	6767
37	• MONERO	7356
38	CHAMA	7851
39	SAN ANTONE RANGER STATION	8900
40	SUNSHINE VALLEY (NEAR)	7500
41	CERRO	7668
42	ANCHOR MINE	10600
43	TIERRA AMARILLA	7466
44	RED RIVER CANYON	8956
45	EAGLE ROCK RANGER STATION	[illegible]
46	ASPEN GROVE RANCH	9000
47	TRES PIEDRAS	8076
48	• ELIZABETHTOWN	8465
49	BATEMAN'S RANCH	8900
50	SERVILLETA (NEAR)	7000
51	VALLECITOS	7200
52	• THERMA (NEAR)	8219
53	TAOS CANYON	8959
54	GAVILAN (NEAR)	7000
55	TAOS	6983
56	EL RITO	
57	• LINDRITH	6900
58	• AURORA	8849
59	• BLACK LAKE	8348
60	CAPULIN RANGER STATION	7200
61	• HAYNES	6600
62	EMBUDO	5809
63	REGINA	7450
64	• CHACON	8510
65	PENASCO	[illegible]
66	LA JARA RANGER STATION	712[illegible]
67	TRUCHAS	7935
68	ESPANOLA	5590
69	CUNDIYO	6889
70	SELSOR RANCH	8500
71	HOT SULPHUR SPRINGS	
72	ALAMOS RANCH	7800
73	NAMBE	[illegible]
74	FRIJOLES CANYON	6200

PRECIPITATION STATIONS

NO.	STATION	ELEVATION
75	LEE RANCH	9000
76	JEMEZ SPRINGS	6100
77	• WINSOR'S RANCH	8000
78	BLAND	7050
79	SANTA FE	7013
80	SANTA FE CANYON	8100
81	• CROWNPOINT	6800
82	WOODBURY	
83	• FORT WINGATE	6997
84	GALISTEO	6074
85	• Mc GAFFEY RANGER STATION	8000
86	BERNALILLO	5042
87	BLUEWATER	6732
88	DIENER	9000
89	• STANLEY (NEAR)	6317
90	SAN RAFAEL	[illegible]
91	ALBUQUERQUE	5196
92	SAN FIDEL	6100
93	TIJERAS CANYON R STATION	6450
94	• BARTON	6875
95	LAGUNA	5840
96	RIO GRANDE INDUST SCHOOL	5000
97	• MORIARITY (NEAR)	[illegible]
98	REA RANCH	9820
99	• TAJIQUE (NEAR)	7100
100	• ESTANCIA (NEAR)	6300
101	LOS LUNAS (NEAR)	4900
102	• MOUNTAINAIR	6475
103	BERNARDO	4731
104	• DATIL	7500
105	MAGDALENA	[illegible]
106	• MONTE PRIETO	6100
107	SOCORRO	4600
108	ROSEDALE (NEAR)	6600
109	SAN MARCIAL	4447
	ELEPHANT BUTTE-FORT QUITMAN SECTION	
110	GLORIETA RANCH	6300
111	CHLORIDE RANGER STATION	6500
112	HERMOSA	7200
113	ELEPHANT BUTTE DAM	4265
114	• GRAHAM'S RANCH	4696
115	HILLSBORO	5236
116	KINGSTON	6500
117	GARFIELD	4100
118	LAKE VALLEY	5412
119	HATCH	4042
120	JORNADA EXPER RANGE	4150
121	AGRICULTURAL COLLEGE	3863
122	• CAMBRAY	4225
123	CHAMBERINO	3800
124	• NEWMAN	3989
125	• LANARK	4156
126	EL PASO	3778
127	CLINT	3663
128	FORT HANCOCK	3516
129	FORT QUITMAN	3454

• NOT ACTUALLY IN RIO GRANDE DRAINAGE BUT CLOSELY ADJACENT THERETO

SNOW COURSES

NO.	COURSE	ELEVATION
1	UPPER RIO GRANDE	9350
2	LA VETA PASS	9300
3	WOLF CREEK	10000
4	SILVER LAKE	9600
5	RIVER SPRINGS	9340
6	CUMBRES PASS	10000
7	RED RIVER (RIO COLO)	9500
8	RIO NUTRIAS	7900
9	CANJILON	9500
10	TAOS CANYON	9000
11	HOLMAN HILL	9400
12	LEE RANCH	9050
13	ASPEN GROVE	9100

There are very few stations such as Cumbres to give precipitation data for the high mountain areas. But, as shown later, by far the major portion of the Rio Grande flow is derived from the precipitation of these areas. For this reason little opportunity is afforded in the Upper Rio Grande Basin to establish a relationship between precipitation and run-off which can be considered dependable in the estimate of run-off. Most of the precipitation stations are located in the lower areas and although this precipitation is productive of run-off, the derivation of any direct and dependable relation thereto is largely obscured by the irregularities characteristic of the precipitation on the lower areas.

Snow Surveys

Snow surveys for the purpose of forecasting seasonal run-off were initiated in the Upper Rio Grande Basin in 1936. They constitute cooperative projects of Federal and State agencies under the direction of the Bureau of Agricultural Engineering, Department of Agriculture. Of a number of "snow courses" established in the mountains of Colorado in 1935, three are in the upper Rio Grande drainage and were surveyed initially in the spring of 1936. Additional courses in the higher mountains of New Mexico were established in the fall of 1936 and were to be surveyed in 1937. Table 11 lists the snow courses now established in the Rio Grande Basin and their location is indicated on plate 3.

Evaporation

Records of evaporation in the Upper Rio Grande Basin are meager. The longest is that for the station at Elephant Butte Dam, which begins in May 1916 and is continuous to date. This gives the evaporation from free water surface in a class A Weather Bureau evaporation pan. Other stations for which evaporation pan records are available are indicated in table 12. Of these eight stations, only four are maintained at present. The monthly records of evaporation at the stations listed in table 12 are given in tables 118 to 125, inclusive, in Appendix A.

Data on evaporation from water surfaces and soils and on plant transpiration are indispensable to a

TABLE 11.—*Snow courses in the Upper Rio Grande Basin in Colorado and New Mexico*

(Surveyed through Federal and State cooperation under the Bureau of Agricultural Engineering, U. S. Department of Agriculture)

No.	Course	Elevation	County	State	National Forest	Local drainage
1	Upper Rio Grande	9,350	Hinsdale	Colorado	Rio Grande	Rio Grande.
2	La Veta Pass [1]	9,300	do	do	San Isabel	Cuchara Creek.
3	Wolf Creek	10,000	Mineral	do	Rio Grande	South Fork Rio Grande.
4	Silver Lake	9,600	Conejos	do	do	Alamosa Creek.
5	River Springs	9,340	do	do	do	Conejos River.
6	Cumbres Pass	10,000	do	do	do	Cumbres Creek.
7	Red River	9,500	Taos	New Mexico	Carson	Rio Colorado (Red River).
8	Rio Nutrias	7,900	Rio Arriba	do	do	Nutrias Creek.
9	Canjilon	9,500	do	do	do	Canjilon Creek.
10	Taos Canyon	9,000	Taos	do	do	Rio Taos.
11	Holman Hill	9,400	do	do	do	Embudo Creek.
12	Lee Ranch	9,050	Sandoval	do	Santa Fe	Jemez Creek.
13	Aspen Grove	9,100	Santa Fe	do	do	Pojoaque Creek.

[1] Not in Rio Grande drainage but close to the Divide.

TABLE 12.—*Evaporation stations in the Upper Rio Grande Basin*

Station	Location	Altitude	Type of pan	Period of record	Remarks
Wagon Wheel Gap, stations A-1 and A-2.	Near Wagon Wheel Gap dam site on the upper Rio Grande, above San Luis Valley, Colo.	9,600	Weather Bureau class A	August 1919 to October 1924	Maintained in connection with the Wagon Wheel Gap Experiment Station of the U. S. Forest Service. A-1, northern exposure; A-2, southern exposure.
Garnett	18 miles northwest of Alamosa, in San Luis Valley, Colo.	7,576	do	June 1927 to October 1928, April 1930 to November 1931.	Maintained by the Colorado State engineer in connection with the Garnett Evapo-Transpiration Experiment Station.
Near Therma	On west shore of Eagle's Nest Reservoir in Taos County, N. Mex.	8,219	do	February 1930 to December 1932, April 1934 to December 1936.	New Mexico State engineer records; U. S. Weather Bureau records.
Santa Fe	At Santa Fe, N. Mex.	7,013	do	May 1913 to November 1914, January 1917 to October 1933.	Do.
Los Griegos	5 miles northwest of Albuquerque, N. Mex.	4,980	do	September 1926 to December 1928, January 1930 to March 1932.	Previous to December 1928 maintained in connection with evapo-transpiration experiment station of Middle Rio Grande Conservancy District; subsequently maintained by New Mexico State engineer.
Elephant Butte Dam	At Elephant Butte Dam, N. Mex.	[illegible]	do	May 1906 to December 1936	Maintained by U. S. Bureau of Reclamation; reported by U. S. Weather Bureau.
Jornada	18 miles northeast of Las Cruces, N. Mex.	4,150	Floating, 36 inches square, 18 inches deep.	June 1929 to June 1932, January 1935 to December 1936.	Maintained in connection with Jornada experimental range of the U. S. Forest Service.
Agricultural College	At New Mexico College of Agriculture and Mechanic Arts, near Las Cruces.	3,863	Weather Bureau, class A	September 1918 to December 1936.	U. S. Weather Bureau records.

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Evaporation

Records of evaporation in the Upper Rio Grande Basin are meager. The longest is that for the station at Elephant Butte Dam, which begins in May 1916 and is continuous to date. This gives the evaporation from free water surface in a class A Weather Bureau evaporation pan. Other stations for which evaporation pan records are available are indicated in table 12. Of these eight stations, only four are maintained at present. The monthly records of evaporation at the stations listed in table 12 are given in tables 118 to 125, inclusive, in Appendix A.

Data on evaporation from water surfaces and soils and on plant transpiration are indispensable to a

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3	Wolf Creek	10,000	Mineral	do.	Rio Grande	South Fork Rio Grande.
4	Silver Lake	9,600	Conejos	do.	do.	Alamosa Creek.
5	River Springs	9,340	do.	do.	do.	Conejos River.
6	Cumbres Pass	10,000	do.	do.	do.	Cumbres Creek.
7	Red River	9,500	Taos	New Mexico	Carson	Rio Colorado (Red River).
8	[illegible] Nutrias	[illegible]	Rio Arriba	do.	do.	Nutrias Creek.
9	Canjilon	[illegible]	do.	do.	do.	Canjilon Creek.
10	Taos Canyon	9,000	Taos	do.	do.	Rio Taos.
11	Holman Hill	9,400	do.	do.	do.	Embudo Creek.
12	Lee Ranch	[illegible]	Sandoval	do.	Santa Fe	Jemez Creek.
13	Aspen Grove	9,100	Santa Fe	do.	do.	Pojoaque Creek.

[1] Not in Rio Grande drainage but close to the Divide.

TABLE 12.—*Evaporation stations in the Upper Rio Grande Basin*

Station	Location	Altitude	Type of pan	Period of record	Remarks
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Garnett	18 miles northwest of Alamosa, in San Luis Valley, Colo.	[illegible]	do.	June 1927 to October 1928, April 1930 to November 1931.	[illegible] in connection with the Garnett Evapo-Transpiration Experiment Station.
Near Therma	On west shore of Eagle's Nest Reservoir in Taos County, N. Mex.	8,219	do.	February 1930 to December 1932, April 1934 to December 1936.	[illegible] Weather Bureau records.
Santa Fe	At Santa Fe, N. Mex.	7,013	do.	May 1913 to November 1914, January 1917 to October [illegible]	Do.
Los Griegos	5 miles northwest of Albuquerque, N. Mex.	[illegible]	do.	September 1926 to December 1928, January 1930 to March 1932.	Previous to December 1928 maintained in connection with evapo-transpiration experiment station of Middle Rio Grande Conservancy District; subsequently maintained by New Mexico State engineer.
Elephant Butte Dam	At Elephant Butte Dam, N. Mex.	[illegible]	do.	[illegible]	[illegible]
Jornada	18 miles northeast of Las Cruces, N. Mex.	[illegible]	Floating, 36 inches square, 18 inches deep.	June 1929 to June 1932, January 1935 to December 1936.	Maintained in connection with Jornada experimental range of the U. S. Forest Service.
Agricultural College	At New Mexico College of Agriculture and Mechanic Arts, near Las Cruces.	[illegible]	Weather Bureau class A	[illegible]	U. S. Weather Bureau records.

comprehensive determination of the consumptive use of water. The Garnett Experiment Station in San Luis Valley and the Los Griegos Experiment Station near Albuquerque were established and maintained respectively by the Colorado State Engineer and the Middle Rio Grande Conservancy District in cooperation with the Bureau of Reclamation, to determine evaporation not only from free water surfaces but also from soils with varying depths to ground water, as well as the evapo-transpiration losses by native vegetation. The data of these experiments are reviewed and taken into consideration in the determinations presented in part III of this report. To obtain additional data of this character to cover the widely varying conditions from the northern to the southern limits of the upper basin, the Bureau of Agricultural Engineering established and maintained in 1936, as a part of the Rio Grande joint investigation, a number of evaporation and evapo-transpiration stations. They included the Parma, Wright, San Luis Lakes, East Henry, Asay, and West stations in the San Luis section; the El Vado Dam, Simms' Ranch, Isleta, and Socorro stations in the Middle section; and the State College and Mesilla Dam stations in the Elephant Butte-Fort Quitman section. These stations are described and the data obtained at them are presented fully in part III.

The evaporation pan data of tables 118 to 125, Appendix A, together with the data of the 1936 stations, have been used in this report to determine mean monthly rates of evaporation applicable to reservoir and lake surfaces in various parts of the upper basin. Description of the derivation and application of these means will be found in the subsequent analyses for various reservoirs. Mean annual rates for evaporation from a lake surface as derived by comparison of all available records and using a coefficient of 0.69 for reduction of class A pan evaporation to lake surface, are given in table 13 for six stations. For comparative purposes, this gives also the corresponding data on altitudes and annual means of temperature and precipitation at these stations.

TABLE 13.—[illegible] Upper Rio Grande Basin

[illegible]

[illegible]	[illegible]	[illegible]	[illegible] perature in [illegible]	[illegible] nual precipitation in feet
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible] 3.4	[illegible]	41	0.6
[illegible]	3.7	[illegible]	[illegible]	1.2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	0.8
[illegible]	[illegible]	[illegible]	60	0.7

[illegible]

Run-Off

Knowledge of the run-off in the Upper Rio Grande Basin is gained from stream-flow measurements. Due probably to the controversies over Rio Grande waters that began as early as the 1890's, stream-flow measurements at key stations on Rio Grande were begun by the Geological Survey at an early date—a fortunate circumstance for present water-supply studies. The station near Del Norte, where Rio Grande enters San Luis Valley, was established in July 1889. That near Lobatos, Colo., which records the Rio Grande flow below the San Luis Valley and near the Colorado-New Mexico State line, was established in June 1899. The station at Embudo, N. Mex., at the head of Espanola Valley, was established in January 1889 and is the oldest station in the basin. The station at Otowi Bridge, formerly referred to as "near Buckman", located at the head of White Rock Canyon and below the confluence of the Rio Chama, was established in February 1895. Measurements at San Marcial, at the lower end of the Middle Valley and upper end of the present Elephant Butte Reservoir, began in January 1895, and the record at El Paso dates back to May 1889. The longest record for any tributary stream is that for the Conejos River near Mogote in Colorado. It begins with May 1903.

The records for these stations are not continuous from the initial date, but the gaps do not seriously impair the utility of the record. The greatest lapse occurred in the Embudo record, a period of 8½ years from 1904 to 1912. The Otowi Bridge and El Paso records have maximum gaps of 3½ years each, Del Norte of 1½ years, and the other stations of a few months only. In general, stations for the measurement of tributary stream flow were established at later dates than those for the main river stations mentioned.

The measurements of stream flow in the Upper Rio Grande Basin have been carried on variously by the Geological Survey, the State Engineering Departments of Colorado and New Mexico, the Bureau of Reclamation, the International Boundary Commission, and other public and private agencies. At present the maintenance of all stations in the upper basin is under the Geological Survey in cooperation with Colorado and New Mexico, with the exception of the Rio Grande stations at San Marcial, El Paso, Tornillo, and Fort Quitman, which are maintained by the International Boundary Commission, and other river stations at Elephant Butte and within the Rio Grande Project, which are maintained by the Bureau of Reclamation.

STREAM MEASUREMENTS IN THE UPPER RIO GRANDE BASIN

NO	STREAM	GAGING STATIONS	DRAIN AREA SQ MI	SOURCE OF RECORD	NO OF YRS
	SAN LUIS SECTION				
1	RIO GRANDE	AT THIRTY MILE BRIDGE	83	G C	25
2	DO	AT WASON	700	G-C	30
3	DO	NEAR DEL NORTE	1320	G C	44
4	DO	NEAR MONTE VISTA	1590	G C	11
5	DO	AT ALAMOSA	* [illegible]	G C	25
6	DO	ABOVE MOUTH TRINCHERA CR		G	
7	DO	NEAR LOBATOS	* 4800	G C	38
8	CLEAR CREEK	BELOW CONTINENTAL RES	45	G C	8
9	DO	NEAR CREEDE	141	G C	0
10	GOOSE CREEK	NEAR WAGON WHEEL GAP	49	G C	2
11	SOUTH FORK RIO GRANDE	AT SOUTH FORK	216	G C	13
12	PINOS CREEK	NEAR DEL NORTE	62	G C	7
13	SAN FRANCISCO CREEK	DO	[illegible]	G	1
14	ROCK CREEK	NEAR MONTE VISTA	38	G C	8
15	DO	NEAR ALAMOSA		G	
16	ALAMOSA CREEK	AT JASPER	64	G C	2
17	DO	NEAR MONTE VISTA	91	G	
18	DO	ABOVE TERRACE RESERVOIR	102		5
19	DO	BELOW DO	20	G C	20
20	DO	NEAR CAPULIN	38	G	1
21	LA JARA CREEK	DO	75	G C	8
22	DO	BELOW EMPIRE CANAL NR SANFORD		G	
23	DO	NEAR MOUTH		G	8
24	TRINCHERA CREEK	ABOVE TURNER'S RANCH	45	G C	4
25	DO	ABOVE MOUNTAIN HOME RES	6	G	14
26	DO	BELOW SMITH RESERVOIR	396	G C	8
27	DO	AT MOUTH NEAR LA SAUSES		G	1
28	SANGRE DE CRISTO CREEK	NEAR FORT GARLAND	176	G C	5
29	DO	ABOVE SMITH RES NEAR BLANCA	25	G C	5
30	UTE CREEK	AT UPPER STA NEAR FT GARLAND	23	G	0
31	DO	NEAR FORT GARLAND	32	G	5
32	CONEJOS RIVER	NEAR MOGOTE	282	G C	33
33	DO	NEAR LA SAUSES	887	G C	6
34	SAN ANTONIO RIVER	AT ORTIZ	[illegible]		5
35	DO	AT MOUTH NEAR MANASSA	348		4
36	LOS PINOS RIVER	NEAR ORTIZ	[illegible]	G C	8
37	CULEBRA CREEK	NEAR CHAMA [illegible]	[illegible]	G	3
38	DO	AT SAN [illegible]	[illegible]		[illegible]
39	DO	AT MOUTH NEAR SAN ACACIO			
	CLOSED BASIN				
40	SAN LUIS CREEK	AT VILLA GROVE			[illegible]
41	DO	NEAR VILLA GROVE	255		5
42	DO	DO		G C	0
43	KERBER CREEK	DO		G C	1
44	DO	DO	39		6
45	SAGUACHE CREEK	NEAR SAGUACHE	490	G C	25
46	NORTH CRESTONE CREEK	NEAR CRESTONE		G C	3
47	SOUTH CRESTONE CREEK	DO		G C	3
48	WILLOW CREEK	DO		G C	3
49	SPANISH CREEK	DO			3
50	CARNERO CREEK	NEAR LA GARITA	[illegible]	G C	8
51	LA GARITA CREEK	DO	6	G C	8
52	COTTONWOOD CREEK	NEAR CRESTONE		G-C	3
53	DEADMAN CREEK	DO		G C	3
54	SAND CREEK	DO		G	1
	MIDDLE SECTION				
55	RIO GRANDE	BELOW TAOS JUNCTION BRIDGE	* 6550	G N	2
56	DO	AT EMBUDO	* 7327	G N	37
57	DO	AT OTOWI BRIDGE	* [illegible]303	G N	38
58	DO	AT COCHITI	* [illegible]661	G N	12
59	DO	AT SAN FELIPE	* [illegible]786	G N	11
60	DO	AT ISLETA	* [illegible]5002	G	1
61	DO	NEAR BERNARDO BRIDGE		G	1
62	DO	AT SAN ACACIA	* 23 [illegible]97	G	1
63	DO	AT SAN MARCIAL	* 24 [illegible]76	G N	42
64	COSTILLA RIVER	AT COSTILLA RESERVOIR		NEEL	7
65	DO	NEAR COSTILLA	229	NEEL	9
66	DO	AT MEYER'S UPPER BRIDGE	230	OSGOOD	3
67	DO	NEAR MOUTH	287	G	0
68	RIO COLORADO	NEAR QUESTA	[illegible]	G N	23
69	DO	BELOW QUESTA	67	G-N	7
70	RIO HONDO	NEAR VALDEZ		G	2
71	DO	AT VALDEZ	38	G N	19
72	DO	AT ARROYO HONDO	7	G N	22
73	RIO PUEBLO DE TAOS	NEAR TAOS	67	G N	5
74	DO	AT TAOS		G	
75	RIO TAOS	AT LOS CORDOVAS	359	G N	27
76	N CH RIO PUEBLO DE TAOS	AT TAOS		G	
77	RIO LUCERO	NEAR ARROYO SECO	[illegible]	G-N	8
78	DO	DO DO DO BELOW DIVERSIONS		G	3
79	RIO FERNANDO DE TAOS	NEAR TAOS	64	G N	16
80	RIO RANCHOS DE TAOS	NEAR RANCHOS OF TAOS	49	N	7
81	PUEBLO CREEK	NEAR PENASCO		G	
82	EMBUDO CREEK	AT DIXON	305	G N	13
83	RIO CHAMA	AT CHAMA		G N	4
84	DO	AT PARK VIEW	405	G N	15
85	DO	NR TIERRA AMARILLA (AT EL VADO)	873	G N	8
86	DO	NEAR TIERRA AMARILLA		G	1
87	DO	NEAR CHAMITA	3202	G N	24
88	BRAZOS RIVER	NEAR BRAZOS		N	3
89	DO	AT BRAZOS		G N	
90	WILLOW CREEK	NEAR PARK VIEW		G	1
91	RIO CANJILON	NEAR CANJILON	[illegible]6	N	1
92	EL RITO CREEK	NEAR EL RITO	52	G	6
93	RIO OJO CALIENTE	AT LA MADERA	344	G	5
94	RIO VALLECITOS	AT VALLECITOS	[illegible]	G N	4
95	SANTA CLARA CREEK	NEAR SANTA CLARA		G	1
96	RIO SANTA CRUZ	AT CUNDIYO	86	G N	7
97	NAMBE CREEK	NEAR NAMBE	37	G	4
98	DO	AT POJOAQUE		G	1
99	RIO TESUQUE	ABOVE DIVERSIONS NR SANTA FE		G	1
100	DO	AT TESUQUE BRIDGE DO DO DO		G	1
101	RITO TESUQUE	NEAR SANTA FE		G	
102	SANTA FE CREEK	MONUMENT ROCK NR SANTA FE		G N	0
103	DO	NEAR SANTA FE	22	G N	24
104	DO	AT SANTA FE	40	G N	4
105	ARROYO HONDO	NEAR SANTA FE	14	G N	0
106	JEMEZ CREEK	NEAR JEMEZ		G	
107	DO	NEAR SAN YSIDRO	854	N	2
108	DO	NEAR BERNALILLO		G	
109	RIO PUERCO	AT RIO PUERCO	4795	G N	7
110	LA JARA CREEK	NEAR LA JARA		G	2
111	BLUEWATER CREEK	NEAR BLUEWATER	235	G N	24
112	DO	AT GRANTS		G N	3
113	SAN JOSE RIVER	NEAR GRANTS		G	1
114	DO	NEAR SAN FIDEL		G	1
115	DO	NEAR CASA BLANCA		G	
116	DO	NEAR SUWANEE	2765	G N	6
	ELEPHANT BUTTE-FORT QUITMAN SECTION				
117	RIO GRANDE	BELOW ELEPHANT BUTTE DAM	* 25923	R G	22
118	DO	ABOVE PERCHA DAM	* 272[illegible]8	R N	15
119	DO	ABOVE LEASBURG DAM	* 28086	R N	3
120	DO	AT EL PASO	* 294[illegible]3	[illegible]	44
121	DO	AT TORNILLO BRIDGE		G R	3
122	DO	NEAR FORT HANCOCK		G	4
123	DO	AT FORT QUITMAN	* 3[illegible]44	G	3
124	ALAMOSA RIVER	NEAR MONTICELLO	385	G N	7
125	LAS PALOMAS RIVER	NEAR LAS PALOMAS	93	N	
	*** **STREAM MEASUREMENTS IN THE SAN JUAN BASIN**				
126	SAN JUAN RIVER	NEAR PAGOSA SPRINGS		G	2
127	DO	AT PAGOSA SPRINGS	287	G	6
128	WEST FORK SAN JUAN RIVER	NEAR PAGOSA SPRINGS		G	2
129	RIO BLANCO	DO		G	2
130	RITO BLANCO	DO			2
131	NAVAJO RIVER	NEAR CHROMO			2
132	DO	AT EDITH	165	G N	7
133	LITTLE NAVAJO RIVER	AT CHROMO		G	2
134	ANIMAS RIVER	AT HOWARDSVILLE	56		2
135	CEMENT CREEK	NEAR SILVERTON	[illegible]4		2
136	MINERAL [illegible]	DO	44		2

Plate 4 lists the upper basin gaging stations for which records are available, indicates the source or agency which has published the records, gives the drainage areas in square miles above the stations, and shows the period for which the records are available. The stations are grouped to the drainages of the three principal areas, San Luis, Middle, and Elephant Butte-Fort Quitman sections. In each section the main river stations are given first, followed by the tributary stations. The stations are numbered consecutively as listed and these numbers are shown for identification on plate 1. At the end of the list of plate 4, a small group of stations in the San Juan River Basin is tabulated. These are stations established and maintained by the Geological Survey in cooperation with Colorado and New Mexico as a part of the Rio Grande joint investigation to furnish run-off data needed in connection with the investigation of projects for the diversion of San Juan Basin waters to the Rio Grande Basin.

The monthly run-off in acre-feet, for the period of record to January 1936, for the stations listed on plate 4 is given in the tables of Appendix A. The sources of the data are indicated in the footnotes for each table. As the daily discharge records for 1936 will appear in the Water Supply Papers of the Geological Survey, no separate publication is made for the present report.

Run-Off at Key Stations, 1890–1935

As previously indicated, there are several stations with long-time records which are key stations with respect to a study of the water supply in the Upper Rio Grande Basin. These are the main-river stations which record the inflow to and outflow from the San Luis, Middle, and Elephant Butte-Fort Quitman sections and those near the sites of major reservoir developments, present and proposed. Since the record for the Del Norte station goes back to 1889 and the records for the other principal stations nearly or quite as far back, it was considered feasible and highly desirable to extend the records and fill in all missing periods with estimates obtained by proper methods in order to derive for key stations a complete monthly record for the 46-year period, 1890–1935. This was done, and the recorded flows plus the estimates to complete the 46-year period are given in tables included in Appendix A, for the following stations: Rio Grande at Wason, Del Norte, Alamosa, Lobatos, Embudo, Otowi Bridge, San Marcial, and El Paso; Conejos River near Mogote; and Rio Chama above El Vado Reservoir. The Rio Grande station at Wason is within the Wagon Wheel Gap Reservoir site. The estimates to extend the records or to fill in missing periods were based on curves of monthly run-off relations to other stations or on mean monthly distribution relations and are explained in detail in the footnotes for each table.

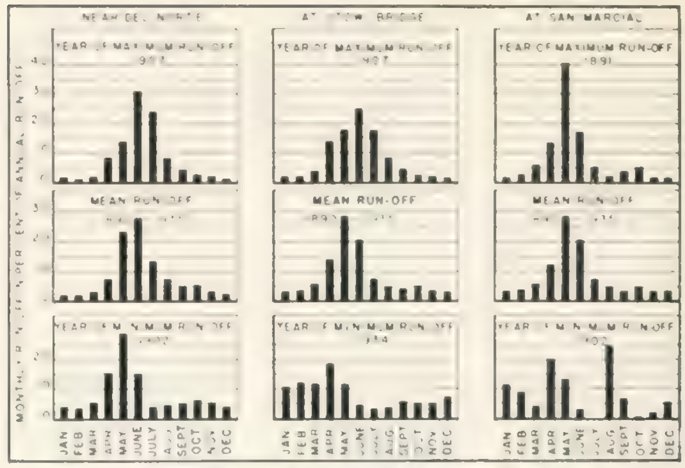


FIGURE 5.—Characteristics of run-off at key Rio Grande gaging stations.

The tables for these key stations show the mean annual and mean monthly run-off for the 46-year period 1890–1935, the monthly mean in percent of the mean annual, and the annual run-off in percent of the mean annual. Except for Del Norte, the Rio Grande stations do not wholly represent direct mountain run-off, but record the flow which has passed or is returned from upper irrigated areas plus intermediate tributary inflow. Tables 14 and 15 summarize the characteristic data for Del Norte, Lobatos, Embudo, Otowi Bridge, and San Marcial, selected as representative stations to show the main river run-off over a 46-year period. Figure 5 gives the characteristics of run-off for a maximum, mean, and minimum year for Del Norte, Otowi Bridge, and San Marcial stations, as representative of the run-off at the head, respectively, of the main irrigated areas of the San Luis, Middle, and Elephant Butte-Fort Quitman sections.

TABLE 14.—*Variation in annual run-off at Rio Grande gaging stations, 1890–1935*

Gaging station	Mean annual run-off in acre-feet	Maximum annual run-off in 46-year period			Minimum annual run-off in 46-year period			Flow factor in percent [1]
		In acre-feet	In percent of mean annual	Year	In acre-feet	In percent of mean annual	Year	
Near Del Norte	707,100	[illegible]	[illegible]	1907	249,300	[illegible]	[illegible]	[illegible]
Near Lobatos	550,200	[illegible]	[illegible]	[illegible]	[2] 98,700	[illegible]	1902	[illegible]
At Embudo	860,100	1,977,000	230	1907	[illegible]	[illegible]	1934	[illegible]
At Otowi Bridge	[illegible]	[illegible]	[illegible]	1907	380,400	28	[illegible]	49
At San Marcial	1,127,700	[illegible]	221	[illegible]	200,600	[illegible]	1902	15

[1] [illegible]
[2] 98,800 in 1934.

Total Water Production from Run-off, 1890–1935

To arrive at a comprehensive and adequate knowledge of the available water supply in the Upper Rio Grande Basin it was considered desirable to prepare estimates,

TABLE 15.—*Average monthly distribution of annual run-off at Rio Grande gaging stations, [illegible]*

Month	Gaging stations									
	Near Del Norte		Near Lobatos		At Embudo		At Otowi Bridge		At San Marcial	
	Mean run-off									
	In acre-feet	In percent of annual	In acre-feet	In percent of annual	In acre-feet	In percent of annual	In acre-feet	In percent of annual	In acre-feet	In percent of annual
January	13,500	1.91	17,900	3.25	30,600	3.56	37,900	2.80	37,900	3.36
February	12,200	1.73	18,500	3.36	31,000	3.60	[illegible]	3.03	41,600	3.69
March	[illegible]	2.76	31,400	[illegible]	48,300	[illegible]	77,000	5.69	63,400	5.62
April	52,400	7.41	48,600	8.83	82,000	9.53	185,800	13.73	138,500	[illegible]
May	163,200	23.08	128,900	23.43	200,100	23.27	379,300	28.03	318,200	28.22
June	[illegible]	[illegible]	146,000	[illegible]	205,700	23.92	275,100	20.33	[illegible]	20.47
July	92,300	13.05	47,400	8.62	72,800	8.46	94,700	7.00	81,700	7.24
August	[illegible]	7.34	19,900	3.62	39,200	4.56	60,400	4.47	[illegible]	[illegible]
September	34,300	4.85	20,300	3.69	36,000	4.19	51,400	3.80	41,200	3.65
October	36,200	5.12	28,600	5.20	46,900	5.45	62,900	4.65	52,700	[illegible]
November	19,600	2.77	22,400	4.07	35,300	4.10	46,700	3.45	34,400	3.05
December	14,500	2.05	20,300	3.69	32,200	3.74	40,800	3.02	38,400	3.41
Total	707,100	100.00	550,200	100.00	860,100	100.00	1,353,000	100.00	1,127,700	100.00

based on all available stream-flow records, of the total water production from run-off for the principal basin drainages. These estimates were made to cover the 46-year period, 1890–1935. The results are summarized in table 16, which indicates that slightly more than 99 percent of the mean annual water production of the upper basin, totaling 3,064,000 acre-feet, originates in Colorado and New Mexico, and that the production of these two States is very nearly equally divided, Colorado producing 51 percent and New Mexico 48 percent of the basin total. The extensive compilations and detail used in the derivation of the water-production estimates for each unit and section of the basin, from which the summary of table 16 is derived, are presented in Appendix B.

TABLE 16.—*Water production from run-off in the Upper Rio Grande Basin*

[Estimated mean annual natural run-off, 1890–1935]

BY SECTIONS

Basin unit	Drainage area in square miles		Mean annual run-off	
	Contributing	Total	In acre-feet	In percent of basin total
San Luis section:				
Southwest area	2,392		1,258,600	41.08
Southeast area	566		120,400	3.93
Closed basin	1,140		187,700	6.12
Total	4,098	[1] 7,890	1,566,700	51.13
Middle section:				
Northern unit	4,641		947,600	30.93
Southern unit	8,072		385,000	12.56
Total	12,713	19,226	1,332,600	43.49
Elephant Butte-Fort Quitman section:				
San Marcial-Elephant Butte unit	1,747		53,000	1.73
Elephant Butte-Leasburg unit	2,163		58,500	[illegible]
Leasburg-El Paso unit	1,327		30,800	1.01
El Paso-Fort Quitman unit	1,631		22,500	0.73
Total	6,868	6,868	164,800	[illegible]
Total of sections		[1] 33,984	3,064,100	100.00

BY STATES

Colorado		[illegible]	1,566,700	51.13
New Mexico		24,463	1,474,900	48.13
Texas		[illegible]	11,000	[illegible]
Chihuahua, Mexico		834	11,500	0.38
Total of States		[illegible]	3,064,100	[illegible]

[1] Includes closed basin, 2,940 square miles in San Luis Valley, Colo., not tributary.

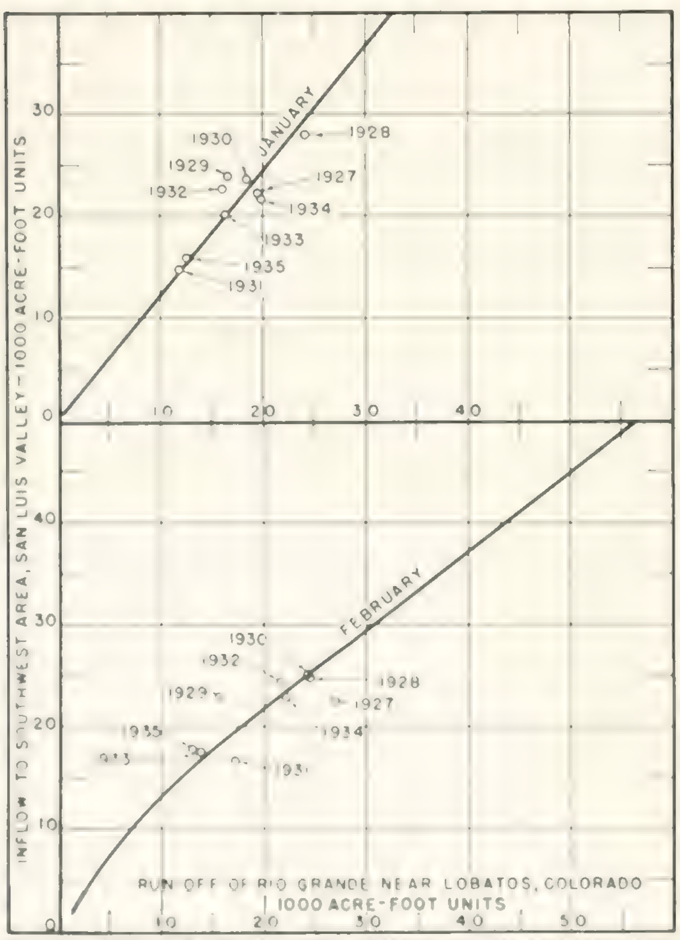
Rio Grande Run-off Corrected for Present Development

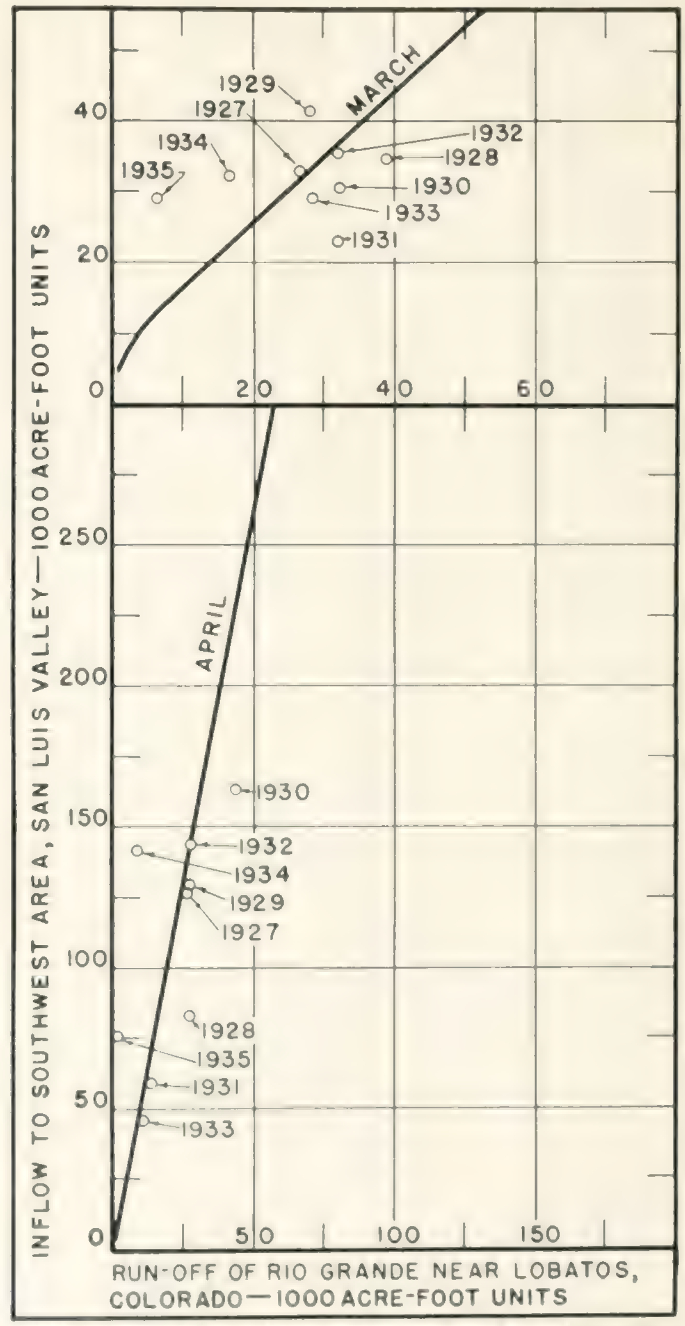
As previously explained, the run-off of Rio Grande near Lobatos represents the residual flow below the San Luis Valley irrigation development. The run-off at Embudo and Otowi Bridge represents this same residual flow plus or minus intermediate tributary inflow or losses, respectively. The run-off at San Marcial represents the residual flow below the Middle Valley irrigation development. In estimates of the water supply for given future conditions it becomes important to determine what the flow, 1890 to 1935, would have been at these gaging stations under present conditions of irrigation development. Put in another way, this means a determination of what the consumption of inflow was in the San Luis and Middle Valleys in this period.

Correction for San Luis Valley development.—While irrigation in San Luis Valley was firmly and widely established prior to 1890, a study of the available data on irrigated acreages indicates a general trend in the direction of expansion until within the past 10 years. The temporary Rio Grande Compact which became effective in 1929 restricts increased use of Rio Grande water in Colorado to an amount offset by drainage return to the river. Accurate annual figures on the total acreage irrigated in San Luis Valley are not avail-

able. However, as set forth in table 58 in the section of this report on irrigation development, surveys of the irrigated acreage made by engineers representing the State engineers of Colorado and New Mexico indicated a total for the valley of 494,200 acres in 1926, 507,471 acres in 1927, 534,806 acres in 1932, and what would have been close to 500,000 acres in 1934 but for the reduction due to water shortage. This suggests that the area irrigated during the period 1927–35 remained substantially constant except for variations due to the availability of water. It is considered, therefore, that this period may be taken as representative of present irrigation development and of the use of water in San Luis Valley, and that use in the past may be referred to use in this period to derive corrections to past stream flow for present conditions.

Since, as previously observed, the run-off to the southeast area of San Luis Valley is practically all consumed in irrigation and does not reach the river, the difference between the total inflow to the southwest area and the flow of Rio Grande near Lobatos may be taken to represent the total consumption of southwest area inflow which includes that of Rio Grande near Del Norte. Although this difference does not represent the total depletion of water in San Luis Valley, it does represent a very substantial part of it and, with respect to corrections to the Lobatos flow for past use, may be taken as a complete index of the use factors governing the river flow at that station. In any one year the water consumption and hence the outflow at Lobatos is influenced to a substantial degree by the extent of available inflow. It was necessary, therefore, to establish the present consumption, or that in the period 1927–35, as related to the inflow. This was done for each month of the year by plotting





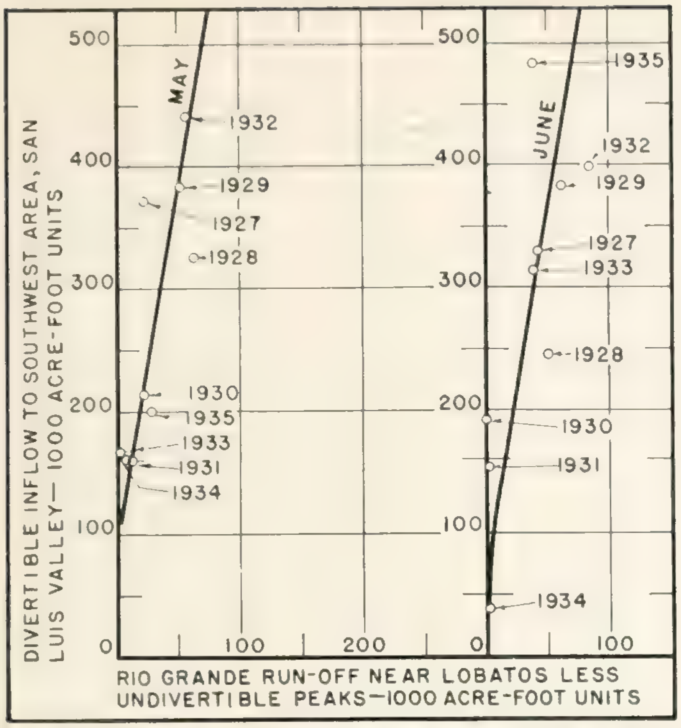


FIGURE 8.—Relation of inflow to outflow, southwest area, San Luis Valley, Colo. For months May and June 1927 to 1935.

the monthly total inflow to the southwest area against the monthly outflow at Lobatos, for the period 1927–35. The total monthly inflow was derived as explained in Appendix B (see table 194) and the outflow was taken

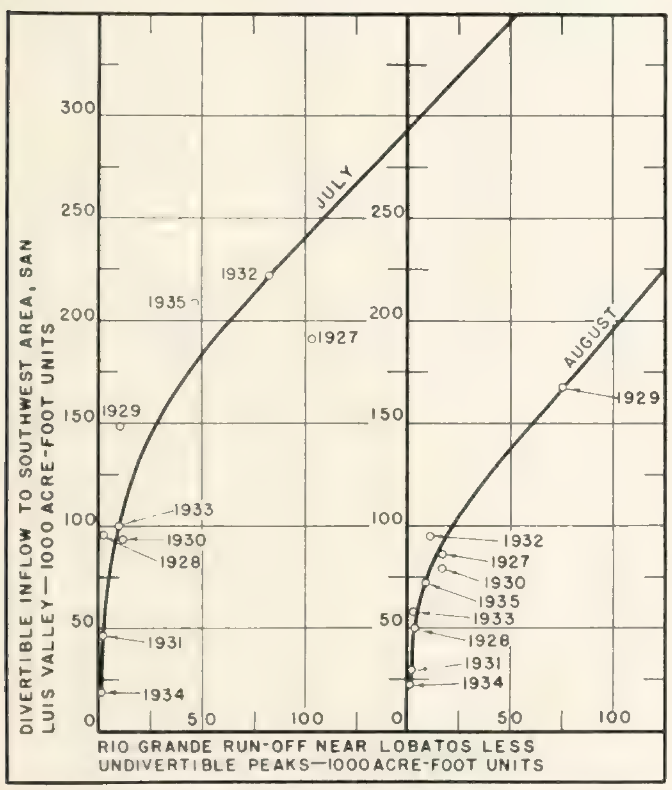


FIGURE 9.—Relation of inflow to outflow, southwest area, San Luis Valley, Colo. For months July and August 1927 to 1935.

from table 131 in Appendix A. The monthly relation curves drawn to fit the plotted points are shown on figures 6 to 11. Although the points for individual years show some deviation from the adopted curves, the latter were so drawn that the algebraic sum of the deviations over the period equals zero. By entering these curves with the monthly inflow to the southwest area in all of the earlier years, 1890 to 1926, as given by table 194 in Appendix B, the corresponding values for the outflow as it would have been in the past under present conditions of irrigation development in the valley were obtained. The difference between these values and the recorded flow at Lobatos as given by table 131, represents the change in depletion or accretion to conform to present

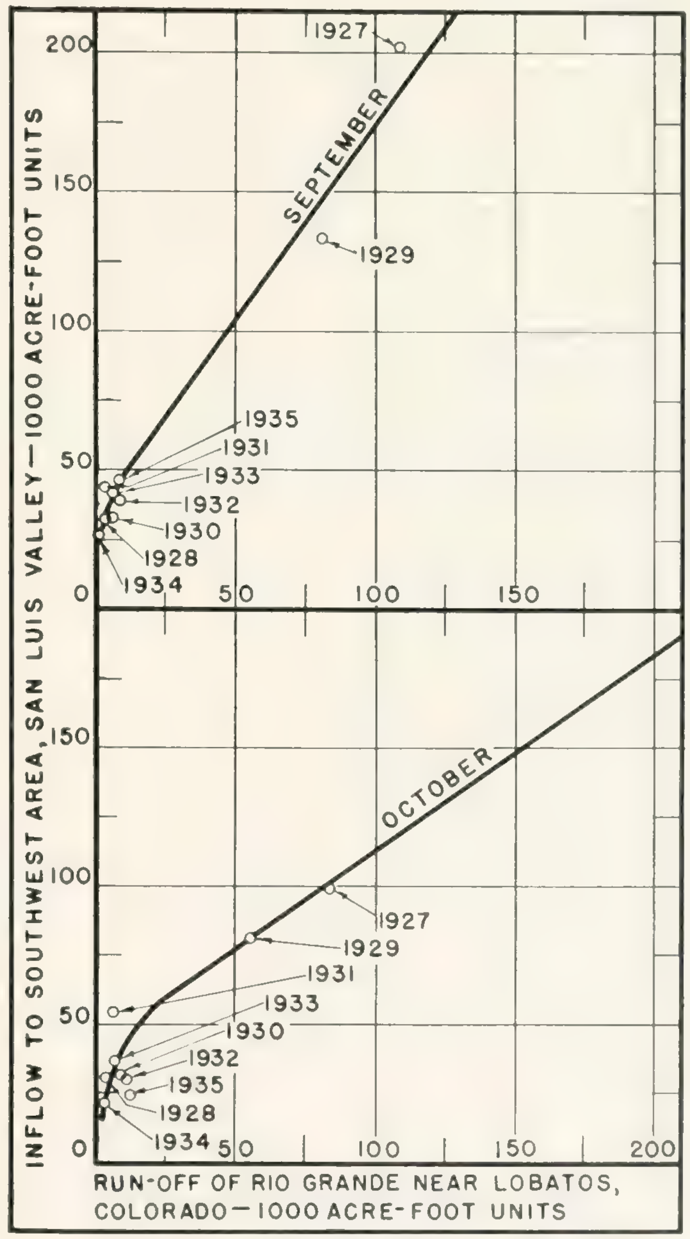
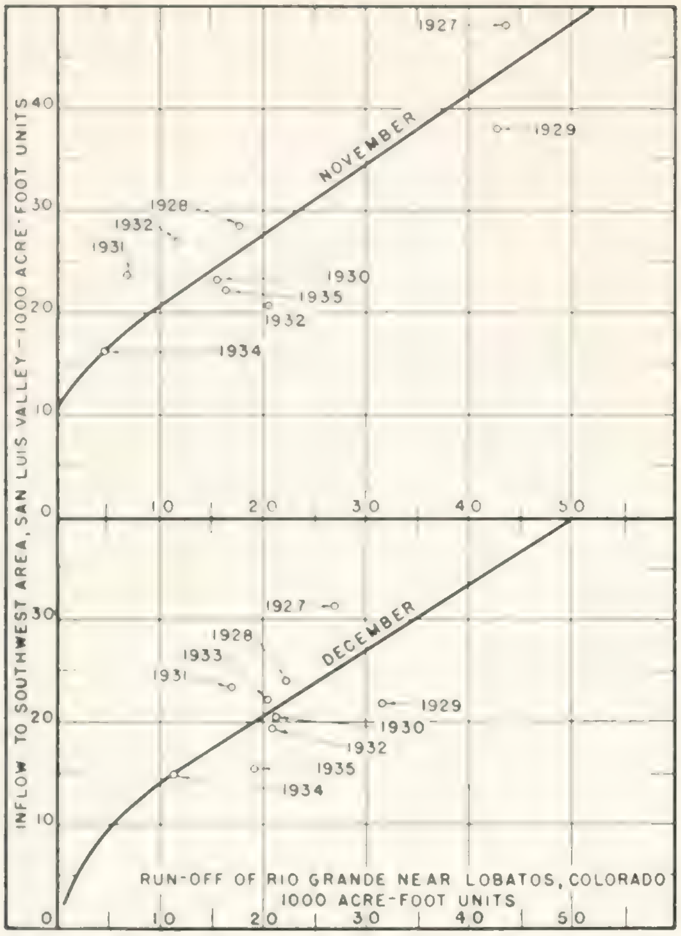


FIGURE 10.—Relation of inflow to outflow, southwest area, San Luis Valley, Colo. For months September and October 1927 to 1935.



conditions. These changes or corrections are given by months in table 17. Those with the minus sign indicate that under present conditions the Lobatos flow would have been less by this amount while those with the plus sign indicate that the flow would have been that much greater. The latter condition is, of course, that which would be anticipated for fall and winter months with the development of drainage and return flow in the later years. It will be noted that the corrections are carried through to December 1935. Present conditions were taken to be represented by the monthly curves plotted for the period 1927–35, and since the points for individual years in this period depart from the curves, these departures gave corrections within this period. The algebraic sum of these last corrections in each of the monthly columns is zero so that as far as the final result is concerned, it is immaterial whether or not they are applied.

During the flood period, May, June, and early July, the discharge of Rio Grande and its tributaries in the San Luis section is frequently, for short intervals, in excess of the diversion capacity of the canals. These flood peaks, therefore, pass from the valley at the Lobatos gaging station and cannot be utilized above that point. A study of the occurrence and volume of these indivertible peaks was made in order to take them into account in the correction of the past Lobatos flow for present development. Inspection of daily discharge records for the peaks of the 1932 and 1935 floods indicated maximum diversions on Rio Grande between Del Norte and Alamosa of approximately 4,000

TABLE 17.—*Corrections to recorded flow of Rio Grande near Lobatos, Colo., to give flow under present irrigation development in San Luis Valley*

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual total
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[2] −80	[1] −33	[1] −15	[1] −8	−9	−2	[illegible]	−162
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[2] −86	[illegible]	[illegible]	[illegible]	−30	[illegible]	+8	−341
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[1] −7	+1	0	[illegible]	+7	+3	−189
[illegible]	+7	[illegible]	[illegible]	[illegible]	−32	[illegible]	0	0	[1] −1	+4	+9	+3	−67
[illegible]	+9	[illegible]	[illegible]	[illegible]	[illegible]	[1] −5	[illegible]	[illegible]	+2	[1] −16	+11	+9	−15
[illegible]	−2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[1] −27	[illegible]	[1] −12	−6	−1	+8	−173
[illegible]	−1	+3	[illegible]	−25	[1] −11	[illegible]	[illegible]	[illegible]	+6	+3	+10	+5	−10
[illegible]	+7	[illegible]	[illegible]	[illegible]	[2] −85	[illegible]	[illegible]	[1] −2	+7	+60	−2	[illegible]	−118
[illegible]	[illegible]	+13	[illegible]	[1] −33	−13	−17	[1] −62	[1] −3	[1] −2	+2	+3	+3	−88
[illegible]	−3	[illegible]	[illegible]	[illegible]	[illegible]	+5	+1	+1	[1] −2	+3	+14	0	[illegible]
[illegible]	−1	[illegible]	+3	[1] −7	[2] −10	[1] −45	+1	[illegible]	[illegible]	+5	+9	−2	−48
[illegible]	−1	−3	[illegible]	+1	[1] −32	[1] −21	[1] −2	[illegible]	[illegible]	+2	[illegible]	+3	−42
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[1] −3	0	0	[illegible]	+1	+8	+8	+11
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[2] −27	−161	−30	0	[illegible]	[illegible]	+7	+4	−180
[illegible]	[illegible]	+2	+8	+8	[illegible]	0	0	+1	[illegible]	+50	+4	0	+90
[illegible]	−3	−3	−19	[1] −18	[2] −172	−148	−1	[1] −3	[illegible]	+1	+4	+1	−361
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[2] −53	[illegible]	−33	[1] −17	−4	[illegible]	−1	−2	−184
[illegible]	−7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	−30	−55	−15	−23	−4	+3	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[1] −22	[illegible]	−23	[1] −10	−11	−3	+1	−100
[illegible]	−3	[illegible]	[illegible]	−21	[illegible]	−91	[illegible]	[illegible]	−58	[illegible]	[illegible]	+27	−299
[illegible]	[illegible]	+2	−17	[1] −47	[2] −75	[2] −14	+2	−2	[illegible]	0	+4	+4	−144
[illegible]	−4	[illegible]	+4	−3	[illegible]	[illegible]	−77	−16	−16	+142	−4	+13	−28
[illegible]	[illegible]	+2	−3	[1] −19	[illegible]	[2] −140	+1	−8	[1] −5	−10	−4	−5	[illegible]
[illegible]	[illegible]	0	−7	[1] −22	[illegible]	[1] −25	+3	+1	+1	−8	+1	+27	[illegible]
[illegible]	+5	[illegible]	−3	[illegible]	[illegible]	−81	−8	[1] −28	−27	−5	−7	−2	−217
[illegible]	−3	+2	−4	[illegible]	[illegible]	−44	−2	[illegible]	−11	−8	−1	−2	−138
[illegible]	−2	−3	−3	[1] −16	[1] −51	+22	+26	−33	−10	+16	−13	0	[illegible]
[illegible]	[illegible]	+5	−2	[1] −18	[1] −41	+10	+26	[illegible]	−4	−7	−12	−9	[illegible]
[illegible]	−4	−6	[illegible]	−2	+4	+7	[1] −5	[illegible]	−7	−3	+1	[illegible]	−24
[illegible]	[illegible]	+5	−4	[illegible]	[2] −95	−21	+8	−9	[illegible]	−5	−4	+6	−173
[illegible]	[illegible]	−3	−4	[illegible]	[illegible]	[illegible]	−3	−5	[1] −6	[1] −14	−13	−9	−177
[illegible]	−11	−3	[illegible]	−12	−22	−201	0	−26	−22	[illegible]	−8	−2	−339
[illegible]	[illegible]	−1	+1	−8	+15	[illegible]	−21	+7	+1	0	+5	+2	−67

TABLE 17.—*Corrections to recorded flow of Rio Grande near Lobatos, Colo., to give flow under present irrigation development in San Luis Valley*—Continued

(Unit: 1,000 acre-feet)

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual total
1923	−2	−1	+3	−6	+27	−34	+13	−20	−16	−22	−6	+7	−57
1924	0	−14	[1] −18	[illegible]	[2] −85	+1	+1	[1] −1	−1	−2	−7	[illegible]	−158
1925	+2	−5	−6	−4	+5	+15	+6	[illegible]	[illegible]	+15	−1	+10	+36
1926	−3	−9	−17	[1] −16	[1] −18	−20	+2	+1	−1	+1	−3	+2	−81
1927	−2	−6	+1	−2	+25	0	−47	−3	+10	−4	+6	+10	−12
1928	−1	−1	−10	−12	−25	−22	+6	0	0	+3	+4	+3	−55
1929	+3	+6	+9	−2	−2	−8	+18	0	−9	0	−8	−10	−3
1930	0	0	−8	[1] −8	−2	+20	−3	[1] −4	−1	[1] −1	[illegible]	−1	−10
1931	0	−3	−14	−2	0	+11	+1	0	+4	+13	+7	+7	[illegible]
1932	+2	+2	−1	0	+2	−30	0	+8	[1] −2	[1] −2	−11	−3	−35
1933	0	+1	−5	[1] −1	+9	+1	0	+1	0	0	+8	+1	+15
1934	−2	−1	+11	+19	+4	−1	0	0	0	+2	0	0	+32
1935	0	+2	+18	+13	[1] −3	+20	+25	0	0	−3	−4	−7	[illegible]
Total	−27	−15	−80	−728	−1,312	−1,874	−346	−340	−232	+99	+9	[illegible]	−4,702

[1] This is the estimated or recorded (subsequent to 1911) discharge of the Rio Grande at Alamosa. On the assumption that development since 1890 has been largely confined to areas irrigated by river diversions above Alamosa, derived depletion corrections exceeding the Alamosa flow were reduced to the amount of that flow as representing the practical limit of depletion for present conditions.
[2] (See footnote 1.) This is the Alamosa flow reduced by the amount of passing indivertable peaks.

second-feet, and on Conejos River and tributaries below the Mogote and Ortiz stations, of about 1,500 second-feet. Past discharge records of Rio Grande near Del Norte and of Conejos River and its tributaries at the Mogote and Ortiz stations were then examined to determine the occurrence and volume of flood peaks in excess of these diversions. In plotting the points for May, June, and July, figures 8 and 9, showing the relation between inflow and outflow for the southwest area in the period 1927 to 1935, both inflow and outflow figures were reduced by the amount of the indivertible peaks. By entering the curves for these months, then, with the past monthly flow determined to have been divertible, the corresponding Lobatos flow less the indivertible peaks was derived. The depletion changes or corrections for May, June, and July, table 17, were then given by subtracting the curve value, increased by the indivertible peaks, from the recorded Lobatos flow.

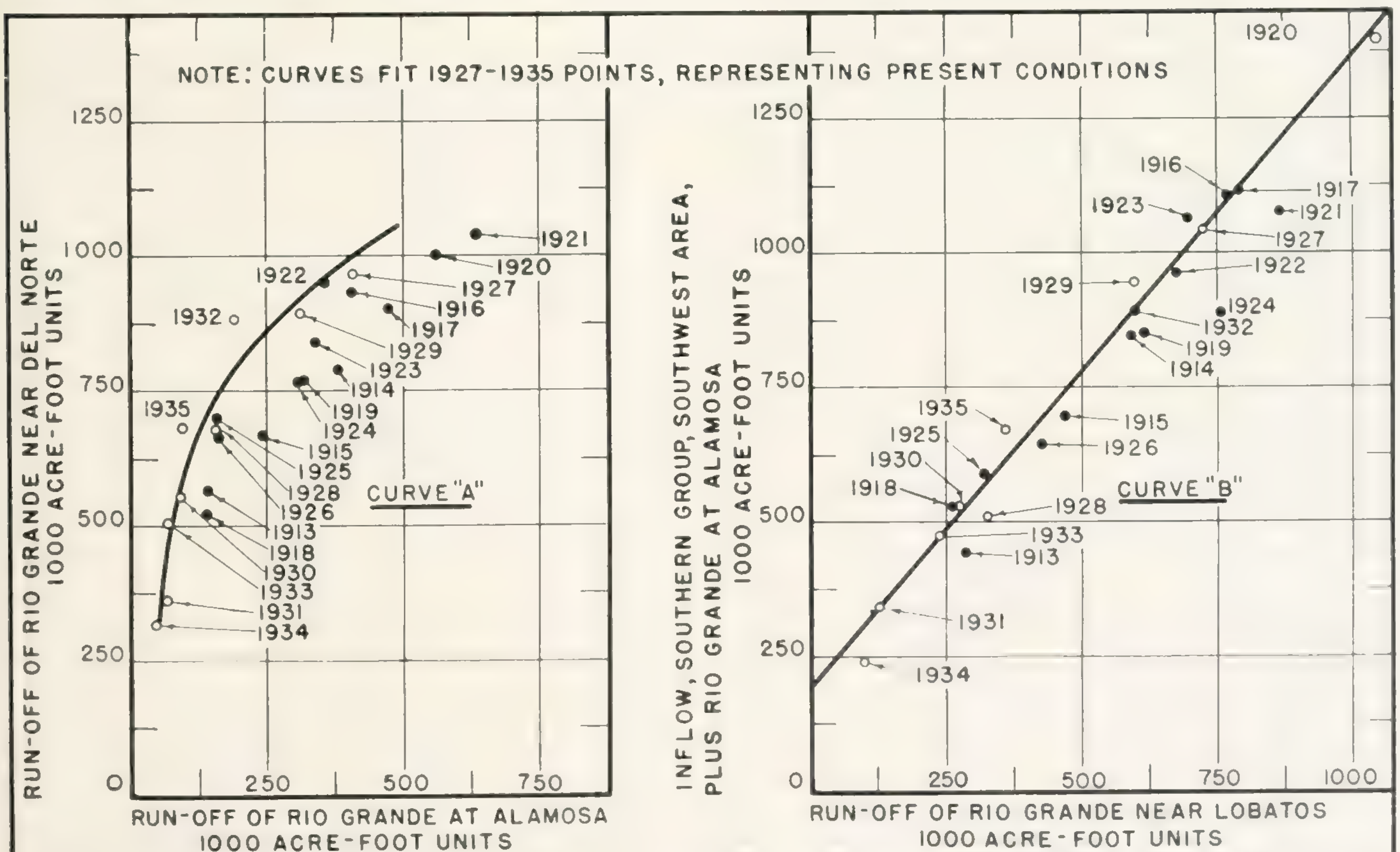
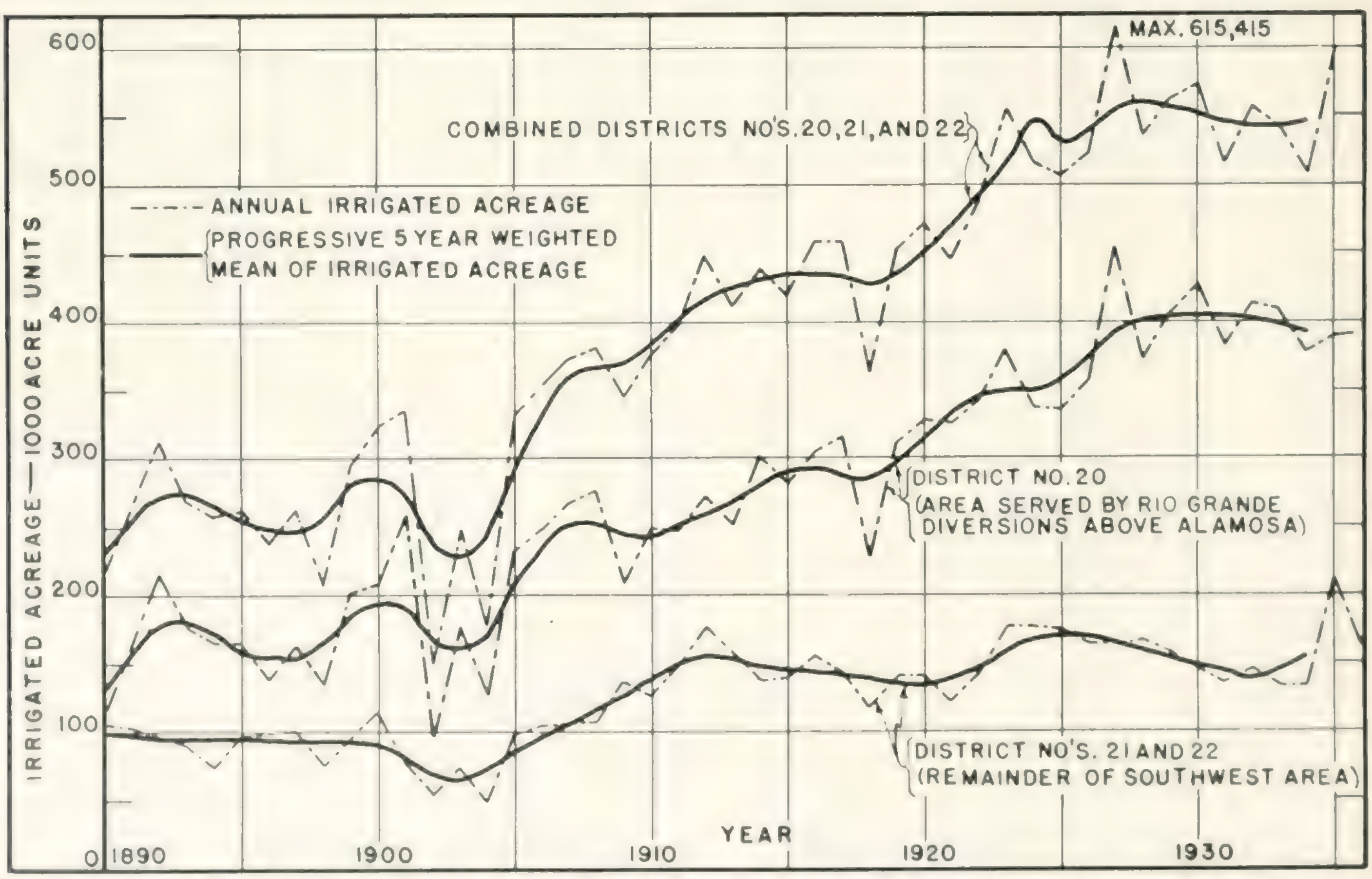


FIGURE 12.—Comparison of inflow and outflow, Rio Grande area above Alamosa and Conejos River-Alamosa Creek area, San Luis Valley, Colo.

A study of all available relevant data seems to indicate that the development which has taken place in San Luis Valley since 1890 has been confined largely to areas which are irrigated by diversions from the Rio Grande above Alamosa. Hence the past flow of the river at Alamosa should represent to a large extent the practical limit by which the flow could have been depleted under present conditions. If, therefore, the corrections derived from the curves as previously described were found to indicate a depletion change greater than the actual flow at Alamosa the corrections were arbitrarily reduced to the amount of the Alamosa flow and they are so shown in table 17. In the case of corrections for May, June, and July, when there were indivertible peaks this modification was made to conform to the flow at Alamosa less the volume of passing indivertible peaks. The record of the river flow at Alamosa does not go back of 1912 and the winter months are generally missing in the earlier years of the record after 1912. As the basis for limitation of the depletion corrections, estimates were made to complete the missing months and to extend this record back to 1890. This was done by reference to Rio Grande flow near Lobatos, using monthly relation curves established for the period of concurrent record. The estimates so derived are given in table 130 in Appendix A.

Some indication of the increase in irrigation development above Alamosa in past years as compared to the correspondingly small change in the Conejos and other portions of the southwest area, is given by the data of figure 12. In curve A the annual run-off of Rio Grande near Del Norte is plotted against that at Alamosa for the period of record of the latter, and in curve B the annual inflow of the southern group in the southwest area (including Conejos, San Antonio, and Los Pinos Rivers and Alamosa and La Jara Creeks, see table 194) plus the flow of Rio Grande at Alamosa is plotted against the Lobatos run-off. In both, the curves are drawn to fit the 1927–35 points as representing present conditions.

Even more strongly indicative of the confinement of increased development largely to the area served by diversions above Alamosa is the comparison of statistics of the acreage irrigated annually in Water District No. 20, comprising chiefly the area served from Rio Grande above Alamosa, and that irrigated in Districts Nos. 21 and 22, comprising the remaining portion of the southwest area. This is shown by the curves of figure 13.



The acreage figures used are those of the water commissioners. As explained in a later section, these figures are not accurate as to the total of the irrigated acreage but in their collection a certain procedure has been consistently followed which has given results which are almost always high. However, for the purpose of showing the trend of irrigation growth as in figure 13 it is believed that the water commissioners' records for Districts 20, 21, and 22 may be used satisfactorily. Smoothed curves representing progressive 5-year weighted means of the irrigated acreage are shown in figure 13 in order to bring out to better advantage the general trends.

The corrections of table 17 applied to the Lobatos record, table 131, gave the estimated run-off of Rio Grande near Lobatos under present conditions of irrigation development in San Luis Valley, as shown by table 18.

The differences between the annual inflow to the southwest area, San Luis Valley, as taken from table 197 in Appendix B and the annual outflow at Lobatos as given by table 131, have been plotted as shown on figure 14. This gives the total consumption or depletion of the inflow to the southwest area including, of course, the heavy diversions from Rio Grande to the Closed Basin. In order to eliminate to some degree the marked annual changes in the depletion due to the varying water supply, and to bring out more clearly the general trend, progressive 5-year weighted means of the depletion were computed and plotted as shown. The curve drawn through these means can probably be taken as a closely representative index of the amount and trend of the water use and irrigation development in San Luis Valley.

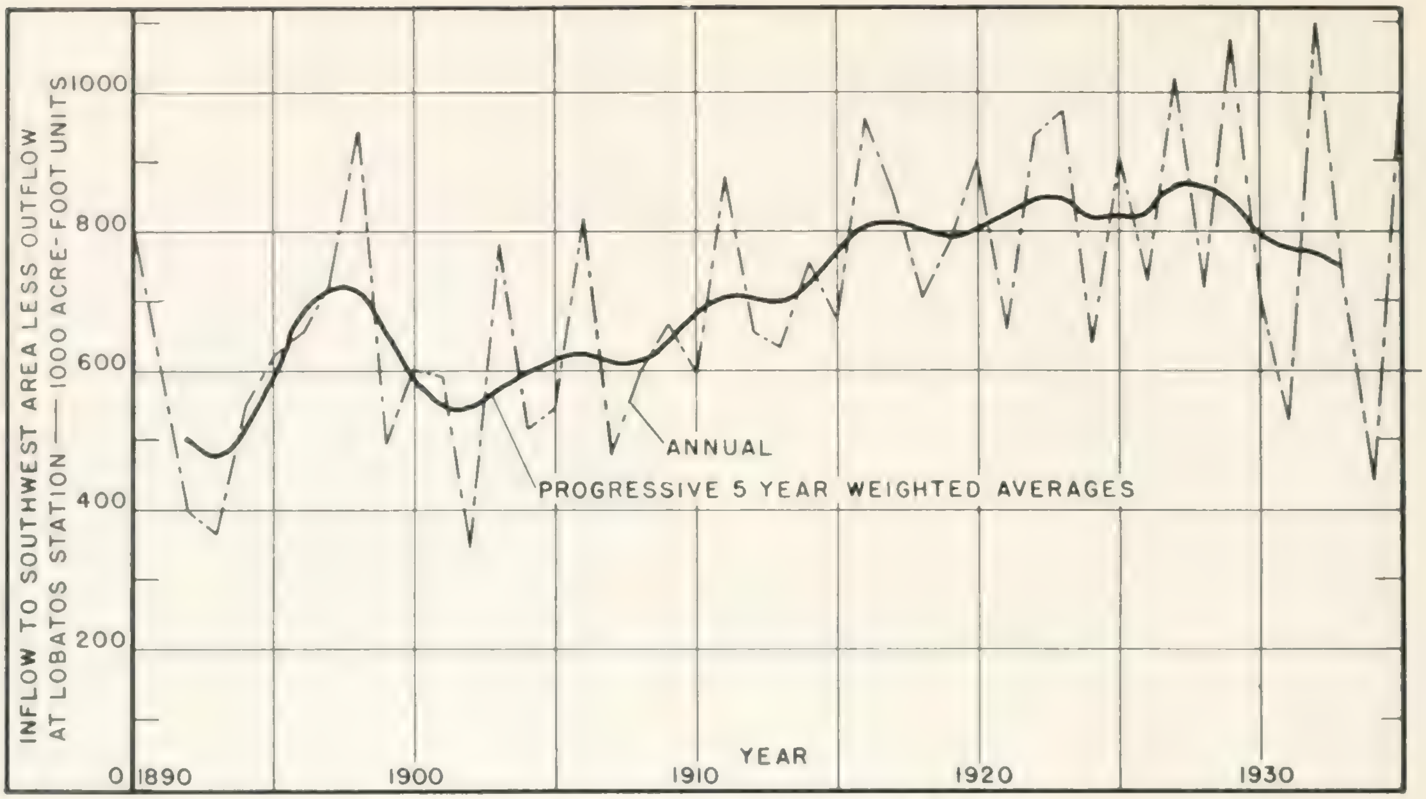
Perhaps of greater significance in the planning of future development and adjustments in the use of water in the Upper Rio Grande Basin, is the curve given on figure 15. This shows the depletion of the southwest area inflow expressed as a percentage of that inflow, annually and by progressive 5-year weighted averages. In other words, this curve shows the variation or trend over the years in the extent to which it has been possible to utilize and consume the available inflow. For example, since about 1921 there has been a fairly steady increase in the percentage of available

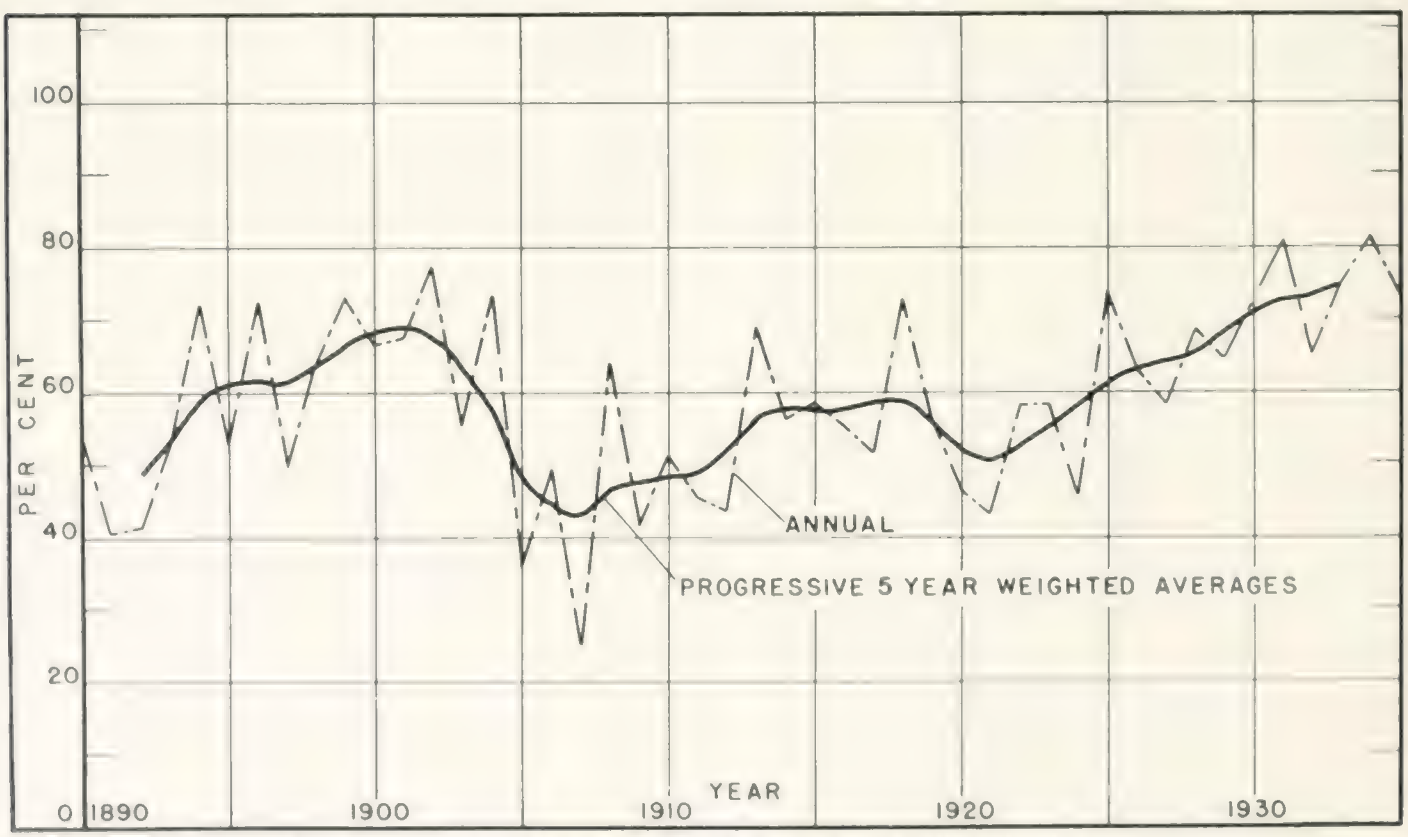
Table 18.—*Estimated run-off of Rio Grande near Lobatos, Colo., under present irrigation development in San Luis Valley*

[Drainage area 4,800[1] square miles. Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in percent of mean
1890	16.0	13.0	41.0	48.0	205.0	91.0	32.0	13.0	8.0	10.0	22.0	28.0	527.0	117.6
1891	20.0	19.0	40.0	54.0	142.0	127.0	47.0	14.0	8.0	50.0	26.0	30.0	577.0	128.8
1892	20.0	20.0	27.0	69.0	123.0	72.0	9.0	2.0	1.0	5.0	11.0	12.0	371.0	82.8
1893	11.0	11.0	21.0	31.0	92.0	61.0	1.0	1.0	3.0	5.0	11.0	12.0	260.0	58.0
1894	12.0	11.0	25.0	28.0	65.0	10.0	1.0	1.0	3.0	9.0	16.0	19.0	200.0	44.6
1895	14.0	13.0	40.0	56.0	82.0	71.0	26.0	16.0	10.0	9.0	23.0	29.0	389.0	[illegible]
1896	20.0	22.0	47.0	40.0	47.0	4.0	2.0	1.0	7.0	10.0	18.0	19.0	237.0	52.9
1897	16.0	13.0	41.0	38.0	139.0	97.0	25.0	3.0	14.0	134.0	56.0	41.0	617.0	137.7
1898	24.0	25.0	42.0	51.0	[illegible]	130.0	50.0	8.0	4.0	5.0	9.0	13.0	430.0	96.0
1899	13.0	12.0	26.0	23.0	27.0	6.0	3.6	4.3	4.1	10.2	29.4	15.7	174.3	38.9
1900	11.3	12.9	21.4	13.2	96.0	63.0	2.2	.7	1.2	6.7	12.3	14.9	255.8	57.1
1901	14.4	10.9	18.3	17.8	92.0	45.0	3.0	2.4	4.6	5.0	16.1	12.2	241.7	54.0
1902	11.1	8.9	18.8	17.3	23.5	3.7	.7	.6	1.0	5.3	9.1	9.7	109.7	[illegible]
1903	4.5	6.4	11.1	18.7	97.0	218.0	42.4	2.9	10.4	8.9	15.3	11.4	447.0	99.8
1904	7.4	8.3	14.8	17.1	7.3	1.2	1.1	9.6	22.7	147.8	21.9	18.4	277.6	62.0
1905	18.5	15.0	36.2	28.0	178.0	282.0	15.7	7.0	3.8	7.3	17.6	16.4	[illegible]	139.6
1906	12.6	12.0	26.9	28.3	152.0	204.0	57.4	13.9	21.2	56.8	44.4	28.7	658.2	146.9
1907	23.7	23.2	40.9	71.0	123.0	250.0	304.0	52.0	28.2	12.4	24.1	25.0	977.5	[illegible]
1908	13.0	12.0	29.7	23.4	39.0	46.4	13.4	15.4	8.2	6.8	11.9	15.8	235.0	52.4
1909	15.4	16.4	24.1	39.1	122.0	178.0	29.3	14.7	82.0	25.4	33.9	54.1	634.4	141.6
1910	23.0	21.7	59.2	74.0	132.0	46.1	4.0	2.6	2.6	7.4	17.6	21.8	412.0	92.0
1911	18.8	17.1	27.1	24.4	129.0	180.0	145.0	19.6	25.6	335.0	43.6	43.7	1,008.9	225.2
1912	25.6	30.0	33.7	31.0	236.0	166.0	50.5	9.3	6.7	7.4	17.6	13.4	627.2	140.0
1913	13.0	12.0	18.0	35.1	39.5	27.7	7.9	3.3	5.1	15.6	25.0	41.0	243.2	54.3
1914	21.0	23.0	28.6	24.5	50.0	74.0	40.4	15.7	21.6	40.1	18.5	17.0	374.4	83.6
1915	15.0	18.0	20.5	33.0	66.0	81.0	37.7	13.1	5.7	7.6	18.5	16.9	333.0	74.3
1916	20.6	23.2	44.8	35.5	113.0	136.0	63.7	50.6	15.5	110.1	52.5	32.0	697.5	155.7
1917	23.0	27.0	29.0	37.8	75.0	306.0	183.0	10.6	5.5	5.1	10.4	13.0	725.4	161.9
1918	13.3	14.5	25.0	13.4	32.1	59.2	16.1	3.2	[illegible]	7.5	20.7	18.7	239.2	53.4
1919	17.8	20.4	30.6	66.0	142.0	42.7	43.7	11.3	6.1	7.2	21.8	29.6	439.2	98.0
1920	21.1	24.4	27.1	16.0	244.0	329.0	116.0	17.1	11.0	9.2	24.4	24.3	863.6	192.8
1921	19.7	23.7	38.6	12.3	70.8	188.0	57.4	37.3	19.3	8.6	23.4	24.8	523.9	116.9
1922	21.6	27.7	34.0	17.5	212.0	198.0	20.0	12.9	5.9	6.0	25.2	26.1	[illegible]	[illegible]
1923	21.1	22.6	30.7	17.8	152.0	126.0	41.6	23.0	45.3	58.6	53.5	47.3	639.5	142.7
1924	24.0	24.5	25.5	109.0	244.0	82.5	11.0	3.6	3.2	5.6	10.2	21.9	565.0	126.1
1925	18.0	21.0	33.6	28.1	43.0	32.7	14.5	12.4	28.4	48.0	34.1	45.2	359.0	80.1
1926	23.6	21.0	21.8	27.4	95.0	87.0	16.7	4.7	2.7	6.0	13.6	25.2	344.7	[illegible]
1927	17.7	21.0	27.7	24.5	121.5	118.0	81.0	13.8	119.0	80.8	49.8	37.0	711.8	158.9
1928	23.2	23.5	29.2	15.7	69.1	39.0	8.6	3.4	4.1	7.6	21.9	25.1	270.4	[illegible]
1929	19.8	21.7	37.0	25.3	118.0	84.2	28.3	76.2	[illegible]	55.8	34.9	21.7	[illegible]	132.8
1930	18.6	24.3	24.6	36.4	36.0	53.0	8.9	12.3	4.5	8.0	13.6	20.2	260.4	58.1
1931	12.0	14.1	18.2	12.0	10.9	14.0	2.3	2.0	7.2	18.9	13.9	24.0	149.5	33.4
1932	18.2	23.7	31.3	28.4	170.0	140.0	86.7	19.0	7.3	9.0	9.8	18.0	561.4	125.3
1933	16.5	14.9	23.7	10.1	42.0	76.6	9.9	3.8	5.8	7.5	19.7	21.5	252.0	56.2
1934	18.0	21.2	27.5	27.7	10.7	.8	.7	1.2	1.9	5.0	4.7	11.4	130.8	29.2
1935	12.6	15.0	24.2	14.9	42.5	195.0	73.7	9.3	9.2	9.3	12.3	12.1	430.1	96.0
Mean	17.3	18.2	29.6	32.8	100.4	105.3	39.9	12.5	15.2	30.8	22.6	23.4	448.0	100.0
Percent of annual	3.86	4.06	6.61	7.32	22.41	23.50	8.91	2.79	3.39	6.88	5.05	5.22	100.0	

[1] Exclusive of closed basin area.


INFLOW TO SOUTHWEST AREA LESS OUTFLOW
AT LOBATOS STATION — 1000 ACRE-FOOT UNITS
1000
800
600
400
200
0
1890
1900
1910
1920
1930
YEAR
ANNUAL
PROGRESSIVE 5 YEAR WEIGHTED AVERAGES


PER CENT
100
80
60
40
20
0
1890
1900
1910
1920
1930
YEAR
ANNUAL
PROGRESSIVE 5 YEAR WEIGHTED AVERAGES

supplies utilized, as shown by figure 15, although in this period there has been little if any general increase in the consumption of inflow, as shown by figure 14. The severe droughts of 1931 and 1934 occurred in this period and although water supplies were greatly diminished, an effort was made to maintain use as shown by the continued rise of the percentage curve (fig. 15). The greater efficiency in use in this period was produced by decreasing waste, by diverting drain waters, and by pumping ground water. The data upon which figures 14 and 15 are based are given in table 19.

TABLE 19.—*Depletion of inflow to southwest area, San Luis Valley, Colo.*

[Unit 1,000 acre-feet]

Year	Inflow to southwest area	Outflow at Lobatos station	Depletion			
			Annual (1)−(2)	Progressive 5-year weighted averages from column (3)[1]	Annual in percent of inflow (3)÷(1)	Progressive 5-year weighted averages from column (5)
	(1)	(2)	(3)	(4)	(5)	(6)
1890	1,490	689	801		53.8	
1891	1,543	918	625		40.5	
1892	958	560	398	503	41.5	48.5
1893	691	327	364	470	52.7	53.1
1894	766	215	551	519	71.9	60.0
1895	1,184	562	622	594	52.5	60.9
1896	899	247	652	682	72.5	62.0
1897	1,458	735	723	719	49.6	60.9
1898	1,459	518	941	723	64.5	64.2
1899	673	180	493	652	73.2	66.4
1900	905	304	601	583	66.4	69.1
1901	874	284	590	548	67.5	68.8
1902	441	99	342	512	77.6	68.7
1903	1,408	627	781	578	55.5	63.5
1904	704	188	516	596	73.3	58.8
1905	1,532	986	546	619	35.6	48.0
1906	1,661	842	819	624	49.3	45.1
1907	1,914	1,436	478	610	25.0	42.1
1908	933	335	598	611	64.1	47.4
1909	1,602	933	669	638	41.8	47.5
1910	1,149	556	593	681	51.6	48.6
1911	1,913	1,037	876	713	45.8	48.7
1912	1,504	849	655	704	43.6	52.0
1913	913	281	632	696	69.2	56.8
1914	1,348	591	757	722	56.2	58.1
1915	1,142	471	671	769	58.8	57.8
1916	1,724	764	960	819	55.7	57.4
1917	1,631	788	843	812	51.7	58.5
1918	964	263	701	802	72.7	59.5
1919	1,392	612	780	784	56.0	55.6
1920	1,943	1,041	902	802	46.4	52.0
1921	1,519	863	656	824	43.2	50.3
1922	1,613	674	939	846	58.2	52.1
1923	1,667	696	971	849	58.2	55.5
1924	1,391	753	638	815	45.9	58.0
1925	1,228	323	905	825	73.7	61.7
1926	1,153	426	727	817	63.1	63.0
1927	1,736	724	1,012	878	58.3	64.0
1928	1,040	325	715	861	68.7	65.1
1929	1,675	598	1,077	847	64.3	68.2
1930	980	270	710	794	72.4	71.2
1931	653	126	527	776	80.7	72.8
1932	1,692	596	1,096	767	64.8	73.3
1933	945	237	708	747	74.9	74.6
1934	539	99	440		81.6	
1935	1,356	360	996		73.4	
46-year mean	1,259	550	709		59.1	

[1] Computed as ⅙ of the sum of 3 times the year under consideration, plus 2 times each of the adjacent years, plus the second year removed in each direction.

Correction for Middle Valley development.—Determination of the depletion or total consumption of inflow in past years in the Middle section, in order to correct past Rio Grande flows to present conditions, is extremely difficult because of the meagerness and uncertainty of records of tributary inflow between Otowi Bridge and San Marcial, the controlling upper and lower river stations, respectively, for the principal unit of water consumption in the Middle section. This tributary inflow, though largely unmeasured, is obviously of such magnitude that total consumption of inflow between Otowi Bridge and San Marcial cannot be derived as the difference in river flow between those stations. The following paragraphs outline the study which was made to derive some estimate of this total consumption of inflow, based upon the very inadequate data available.

As a measure of tributary inflow, investigation was first made of gains in the river flow between intermediate stations. For this purpose there was available the record of the river flow at San Felipe for 1926 to 1936, inclusive. This record was extended to cover 1890–1935 by relating monthly gains between Lobatos and Otowi Bridge and between Lobatos and San Felipe for the period of concurrent record, and estimating the gains to San Felipe for the earlier years from the resulting relation curves. Using this extended record the monthly river gains between Otowi Bridge and San Felipe and between San Felipe and San Marcial were derived as shown in tables 20 and 21. As indicated, the mean annual gains are 81,600 acre-feet from Otowi Bridge to San Felipe and 61,400 acre-feet from San Felipe to San Marcial. This study showed many gains between Otowi Bridge and San Felipe where, for the same months, comparison of Otowi Bridge and San Marcial flows showed losses. The gains in tables 20 and 21 represent the excess of tributary inflow, surface and seepage, over consumption of inflow in the respective river sections, as derived for monthly periods. Inasmuch as the flow of the tributary streams in the Middle Valley is flashy, with flood flows extending over a few days only, a study of gains based on daily river flows would in all probability show higher gains than those of tables 20 and 21. Lack of long time daily records, however, precluded such a study.

The total consumption of inflow in the past, Otowi Bridge to San Marcial, like that in the southwest area of San Luis Valley, has, within limits, varied more or less directly with the available water supply; in the case of the Middle Valley, with both side inflow and river flow at Otowi Bridge, but chiefly the latter. Estimate of past consumption of inflow in the Middle Valley, therefore, involves determination of the relation between Otowi Bridge-San Marcial losses and the Otowi Bridge flow. Assuming that the consumption of inflow, Otowi Bridge to San Marcial, could be taken as closely approaching the indicated Otowi Bridge-San Marcial loss during the frequent periods when tributary inflow has apparently approached zero, study was next directed to the determination of a large number of such losses for

Table 20.—Rio Grande gains between Otowi Bridge and San Felipe, N. Mex.

[Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
[illegible]	0	3.0	0	10.0	25.0	16.0	[illegible]	2.0	0	[illegible]	3.0	5.0	84.0
[illegible]	0	3.0	18.0	15.0	16.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.0	4.0	113.0
[illegible]	0	3.0	20.0	25.0	38.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.0	2.0	106.0
[illegible]	0	2.0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.0	3.0	16.0
[illegible]	0	2.0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.0	[illegible]	13.0
[illegible]	0	[illegible]	15.7	14.0	0	[illegible]	[illegible]	.9	[illegible]	[illegible]	4.4	[illegible]	76.4
[illegible]	[illegible]	[illegible]	4.8	0	0	[illegible]	1.7	0	0	0	2.4	3.0	11.4
[illegible]	0	[illegible]	5.2	14.0	68.0	20.0	14.7	1.6	0	0	.1	1.8	128.3
[illegible]	0	[illegible]	[illegible]	4.0	0	2.0	[illegible]	.8	[illegible]	0	6.4	5.8	37.1
[illegible]	0	[illegible]	3.8	0	0	[illegible]	3.4	0	.9	[illegible]	6.0	4.8	22.3
[illegible]	1.2	[illegible]	[illegible]	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	8.8
[illegible]	0	3.5	0	0	0	0	11.2	1.2	0	0	4.5	3.5	23.9
[illegible]	0	2.8	0	0	[illegible]	0	.3	.8	0	0	.6	3.8	8.3
[illegible]	[illegible]	3.3	28.8	1.0	2.0	55.0	25.0	.4	0	0	.8	2.4	118.7
[illegible]	0	2.8	[illegible]	0	[illegible]	[illegible]	0	7.0	42.0	1.0	[illegible]	[illegible]	63.0
[illegible]	0	4.4	[illegible]	2.0	53.0	14.0	10.3	.3	0	0	[illegible]	4.1	[illegible]
[illegible]	[illegible]	3.0	0	0	25.0	23.0	21.0	2.0	[illegible]	0	[illegible]	[illegible]	90.0
[illegible]	[illegible]	3.0	16.0	17.0	1.0	39.0	[illegible]	[illegible]	0	[illegible]	4.0	4.0	144.0
1908	[illegible]	[illegible]	14.0	[illegible]	0	1.0	11.0	3.0	0	0	[illegible]	3.0	48.0
[illegible]	[illegible]	3.0	0	2.0	12.0	23.0	25.0	4.2	17.0	0	0	1.5	87.7
[illegible]	[illegible]	1.7	10.0	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	0	[illegible]	2.7	21.6
[illegible]	1.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	1.0	43.0	10.5	149.2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	25.0	[illegible]	27.0	1.0	0	[illegible]	.7	2.5	114.8
[illegible]	[illegible]	3.1	[illegible]	0	[illegible]	0	7.2	0	0	[illegible]	3.7	3.8	18.0
[illegible]	2.1	3.2	[illegible]	0	0	6.0	40.0	5.0	0	0	7.0	3.6	[illegible]
1915	0	[illegible]	11.0	5.0	22.0	30.0	17.5	1.8	[illegible]	0	.5	3.3	94.1
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33.0	20.0	22.5	2.0	[illegible]	0	7.2	4.4	124.5
1917	[illegible]	[illegible]	1.2	[illegible]	[illegible]	18.0	11.0	[illegible]	[illegible]	0	.6	2.8	[illegible]
[illegible]	[illegible]	1.3	1.2	0	0	4.0	12.5	0	0	[illegible]	3.0	[illegible]	[illegible]
[illegible]	[illegible]	2.4	13.8	[illegible]	15.0	13.0	46.0	4.1	0	[illegible]	[illegible]	6.9	[illegible]
[illegible]	[illegible]	6.3	15.2	0	65.0	46.0	25.0	.3	0	0	4.5	2.6	166.4
1921	0	2.9	12.0	0	0	45.0	16.0	11.0	4.3	0	2.2	[illegible]	[illegible]
[illegible]	1.5	2.8	[illegible]	0	[illegible]	9.0	11.0	.3	[illegible]	0	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	3.1	0	0	0	5.0	4.8	1.0	8.0	0	[illegible]	[illegible]	[illegible]
1924	[illegible]	[illegible]	0	[illegible]	23.0	11.0	13.6	.8	0	0	3.5	[illegible]	[illegible]
[illegible]	[illegible]	2.9	5.4	0	0	0	10.3	3.2	0	0	5.3	4.4	31.5
[illegible]	11.8	31.1	49.4	72.0	103.0	0	17.2	2.2	0	0	19.4	10.2	319.3
[illegible]	8.2	7.8	[illegible]	0	24.0	27.0	131.0	[illegible]	47.0	6.0	[illegible]	9.1	315.2
[illegible]	2.8	4.5	20.3	[illegible]	[illegible]	14.0	5.4	52.4	.7	3.3	2.7	[illegible]	112.3
[illegible]	0	0	[illegible]	[illegible]	0	[illegible]	25.6	7.0	32.0	7.0	18.8	18.1	108.5
[illegible]	5.3	0	[illegible]	[illegible]	0	9.4	17.2	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0	[illegible]	[illegible]	[illegible]	15.0	0	2.8	.8	3.2	[illegible]	[illegible]	2.8	28.9
[illegible]	.9	[illegible]	[illegible]	[illegible]	27.0	0	17.0	1.2	0	[illegible]	[illegible]	3.7	53.6
[illegible]	[illegible]	4.2	[illegible]	[illegible]	0	21.0	5.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	84.8
[illegible]	[illegible]	[illegible]	[illegible]	0	5.3	0	0	0	0	0	[illegible]	4.1	[illegible]
[illegible]	0	0	[illegible]	2.3	8.0	[illegible]	4.8	[illegible]	11.4	0	[illegible]	[illegible]	[illegible]
[illegible]	1.4	[illegible]	[illegible]	[illegible]	13.2	12.8	17.7	4.6	3.6	.4	[illegible]	4.8	81.6

Table 21.—Rio Grande gains between San Felipe and San Marcial, N. Mex.

[Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1890	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	381.0
[illegible]	0	[illegible]	0	0	0	0	0	0	0	[illegible]	0	[illegible]	[illegible]
[illegible]	11.0	0	0	0	[illegible]	0	0	[illegible]	0	[illegible]	0	[illegible]	11.0
[illegible]	2.0	0	0	[illegible]	[illegible]	0	0	0	0	29.0	0	[illegible]	31.0
[illegible]	3.0	18.8	29.0	[illegible]	[illegible]	0	29.0	87.0	[illegible]	0	[illegible]	0	157.8
[illegible]	9.0	[illegible]	0	[illegible]	0	0	1.7	0	0	21.6	0	[illegible]	39.5
[illegible]	0	0	0	[illegible]	0	0	0	0	77.0	[illegible]	104.0	119.0	451.0
[illegible]	39.9	[illegible]	[illegible]	1.0	0	0	[illegible]	0	0	[illegible]	0	0	105.5
[illegible]	8.9	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	0	0	0	[illegible]
[illegible]	[illegible]	.1	[illegible]	[illegible]	0	0	0	0	16.1	0	[illegible]	0	18.8
[illegible]	4.0	0	[illegible]	[illegible]	0	0	3.3	13.5	9.6	0	0	0	30.4
[illegible]	[illegible]	0	[illegible]	[illegible]	0	[illegible]	[illegible]	14.2	0	[illegible]	[illegible]	[illegible]	14.2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	[illegible]	[illegible]	0
[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	0	0	0	0	[illegible]	[illegible]	3.8	215.6
[illegible]	[illegible]	7.9	10.0	[illegible]	121.0	127.0	0	0	0	0	[illegible]	0	327.3
1906	[illegible]	1.7	13.9	[illegible]	0	0	[illegible]	0	0	0	0	27.1	46.2
[illegible]	.6	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	[illegible]	[illegible]	0	55.3
1908	0	0	[illegible]	0	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	4.4	4.4
[illegible]	4.6	0	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	[illegible]	10.6	4.8	20.0
1910	30.3	9.0	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39.3
[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	0	0	[illegible]	0
[illegible]	5.3	[illegible]	0	[illegible]	[illegible]	0	[illegible]	[illegible]	0	0	[illegible]	[illegible]	5.3
1913	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	[illegible]	[illegible]	[illegible]
1914	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1915	[illegible]	[illegible]	[illegible]	32.0	0	0	11.0	[illegible]	[illegible]	[illegible]	0	[illegible]	43.0
1916	4.8	0	0	0	[illegible]	0	0	[illegible]	[illegible]	6.0	[illegible]	0	10.8
1917	9.6	[illegible]	[illegible]	[illegible]	0	0	0	0	[illegible]	[illegible]	0	0	9.6
1918	1.0	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	[illegible]	0	0	0	1.0
1919	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	[illegible]	0	0	66.4
1920	[illegible]	[illegible]	[illegible]	1.0	0	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	117.7
1921	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	0	[illegible]	[illegible]	0	88.0
1922	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	3.5
1923	[illegible]	0	[illegible]	[illegible]	[illegible]	0	0	0	0	[illegible]	0	0	[illegible]
1924	[illegible]	13.1	[illegible]	34.0	[illegible]	0	[illegible]	[illegible]	0	[illegible]	0	[illegible]	[illegible]
1925	[illegible]	[illegible]	[illegible]	0	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0

TABLE 21.—*Rio Grande gains between San Felipe and San Marcial, N. Mex.*—Continued

[In 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1926	0	0	0	0	[illegible]	36.0	[illegible]	0	0	0	0	[illegible]	[illegible]
1927	[illegible]	0	0	0	[illegible]	0	0	0	0	0	[illegible]	[illegible]	[illegible]
1928	0	0	0	0	[illegible]	0	0	0	0	[illegible]	[illegible]	[illegible]	0
1929	0	[illegible]	0	0	[illegible]	0	0	106.0	128.0	12.0	[illegible]	[illegible]	[illegible]
1930	0	0	0	0	0	[illegible]	0	0	0	0	0	[illegible]	0
1931	3.8	0	0	0	0	0	[illegible]	0	0	13.4	[illegible]	0	17.2
1932	3.6	0	0	0	[illegible]	0	0	18.0	[illegible]	[illegible]	0	0	21.6
1933	.8	0	0	0	[illegible]	37.0	3.5	3.0	13.8	[illegible]	[illegible]	[illegible]	58.1
1934	0	0	0	0	0	0	0	23.7	[illegible]	0	[illegible]	0	[illegible]
1935	12.1	8.4	0	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]
46-year mean	4.2	2.7	3.1	2.8	[illegible]	6.9	4.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

a wide range of Otowi Bridge flows during each month of the year, using daily river discharge data. These losses, in second-feet, were computed for single days at intervals of from 5 to 10 days throughout 35 years of available record for Otowi Bridge and San Marcial, utilizing days when the flow appeared to be uniform and not affected by appreciable volumes of tributary inflow. For the movement of water between Otowi Bridge and San Marcial, a lag of 2 days was allowed for flows exceeding 1,000 second-feet and 3 days for lesser flows. The losses so derived were plotted against the corresponding Otowi Bridge flows using a separate graph for each month of the year as shown by figure 16.

In plotting the points originally a legend was used to segregate the losses to four periods, 1890–1905, 1906–19, 1920–29, and 1930–35. (Differentiation for the period 1930–35 only was finally shown on figure 16.) This was done to furnish a basis for observation of whether any distinct changes or trends in the loss relationship might have occurred over the years. The period 1930–35 covers that of the construction of the irrigation and drainage works of the Middle Rio Grande Conservancy District. Another segregation was for the loss as determined by "seepage runs". In October 1913, January 1924, and October 1926, the New Mexico State engineer's office made a series of measurements of the river flow including, in the section from Otowi Bridge to San Marcial, measurements of all intermediate diversions and inflow. This was done at times when there was uniform river flow so that the results of the seepage run would give as closely as possible the actual river loss and side inflow between Otowi Bridge and San Marcial. The data of these measurements, as taken from published reports, furnished three definite determinations of river loss and side inflow which were plotted as shown on figure 16 for January and October. Inspection of the plotted points shows a wide variation in loss depending upon the supply. The original segregation of points to four periods appeared to give little justification, however, for any deduction of a fixed trend or definite change in the loss relationship over the periods, with possibly one exception. For the winter months November to March there appeared to be some indication of lower losses for given Otowi Bridge flows in the period 1930–35. This is an effect which might be expected with the development of the Middle Rio Grande Conservancy District drainage system in this period.

On each of the graphs, curves were drawn to define for each month the Otowi Bridge flow-inflow loss relationship for the greatest losses, eliminating eratics. These were drawn by enveloping the area of greatest congestion of points, disregarding isolated points representing exceptionally high losses due presumably to unusual circumstances of use or to faulty deduction because of the lack of uniform flow or possible errors in one or the other of the river flow records. In order to estimate the monthly loss or consumption of inflow the curves of figure 16 were converted to give the monthly loss relationship in acre-feet as shown by figure 17. Entering these curves with the monthly flow at Otowi Bridge, 1890 to 1935, corresponding values for the monthly consumption of inflow in this period were obtained. These values were then adjusted to conform to and be consistent with the losses indicated by the Otowi Bridge-San Marcial differences for the months under consideration, and with the results of the previous study of river gains, Otowi Bridge to San Felipe and San Felipe to San Marcial. In the adjustment, side inflow was made to exceed river gains by an amount conservatively estimated to cover consumption in the river section showing a gain. In the case of material gains, slight adjustment was made also to cover greater consumption due to such factors as expanded water surfaces and overflows. The final determinations for the monthly consumption of inflow are shown in table 22. These figures give a mean annual consumption of inflow, 1890 to 1935, of 585,600 acre-feet.

The difference between the consumption figures of table 22 and the corresponding Otowi Bridge-San Marcial differences was credited to tributary inflow which reached the stream either by surface flow or from ground water. The values for the monthly tributary inflow so derived are shown in table 23 and give a mean

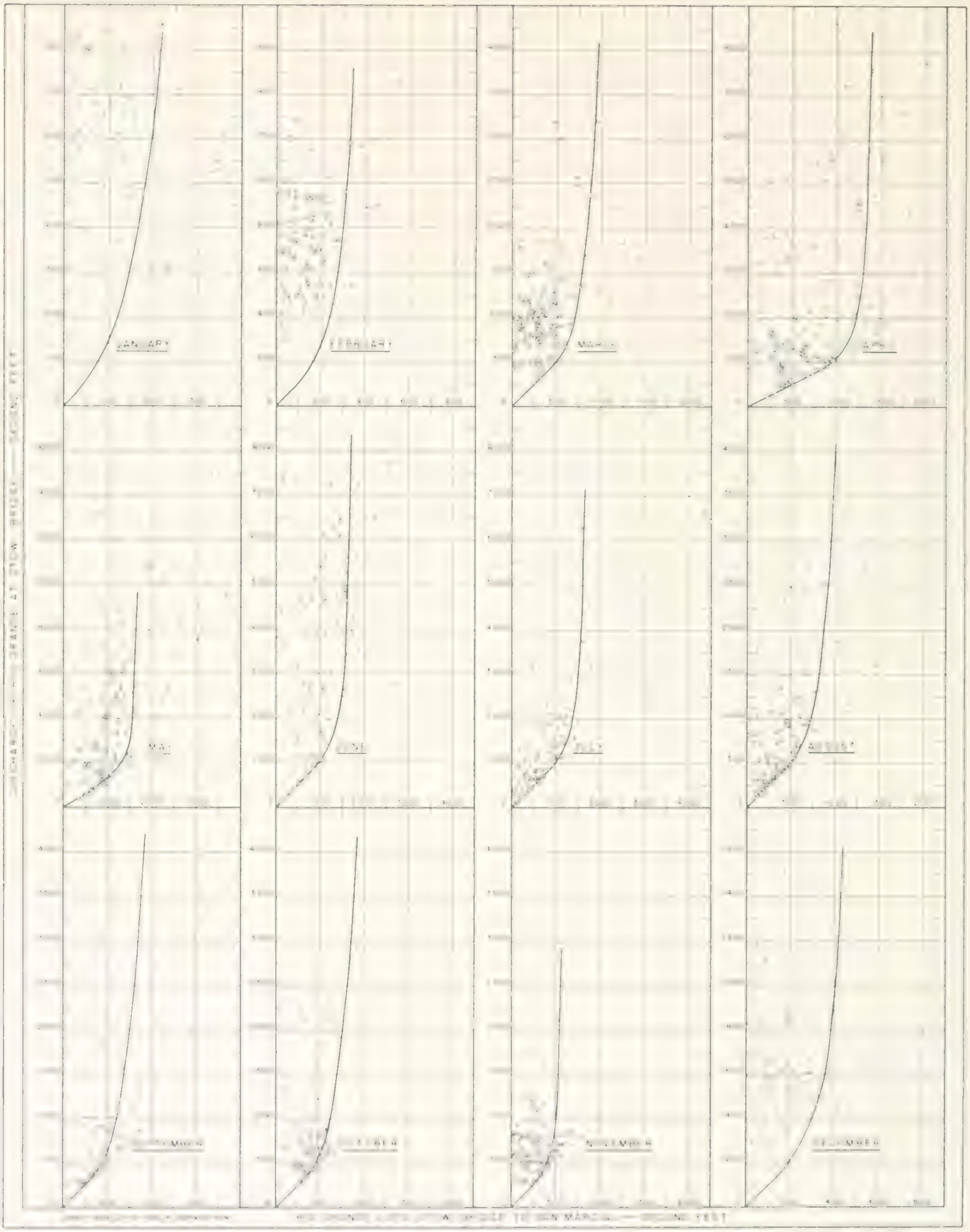

JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

TABLE 22.—*Estimated consumption of inflow to the Middle Valley, Otowi Bridge to San Marcial*

[Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1890	11.0	16.0	41.0	120.0	130.0	97.0	88.0	47.0	[illegible]	12.0	28.0	24.0	676.0
1891	13.0	17.0	49.0	80.0	120.0	100.0	[illegible]	[illegible]	31.0	17.0	34.0	27.0	[illegible]
1892	12.0	17.0	72.0	200.0	104.0	95.0	50.0	[illegible]	8.0	15.0	25.0	17.0	629.0
1893	9.0	14.0	28.0	110.0	97.0	190.0	30.0	18.0	21.0	25.0	22.0	18.0	582.0
1894	9.0	12.0	38.0	74.0	94.0	40.0	29.0	22.0	20.0	25.0	29.0	28.0	410.0
1895	11.0	16.0	47.0	80.0	95.0	95.0	85.0	51.0	31.0	31.0	29.0	23.0	594.0
1896	12.0	16.0	46.0	78.0	89.0	30.0	29.0	16.0	18.0	25.0	24.0	21.0	404.0
1897	11.0	15.0	42.0	105.0	105.0	100.0	76.0	28.0	32.0	49.0	32.0	23.0	[illegible]
1898	10.0	14.0	31.0	80.0	92.0	105.0	90.0	36.0	19.0	22.0	32.0	23.0	554.0
1899	10.0	16.0	60.0	130.0	90.0	24.0	39.0	[illegible]	52.0	[illegible]	42.0	23.0	[illegible]
1900	12.0	15.0	40.0	51.0	95.0	90.0	19.0	10.0	31.0	24.0	26.0	21.0	434.0
1901	10.0	16.0	37.0	67.0	96.0	85.0	47.0	42.0	28.0	26.0	23.0	20.0	497.0
1902	11.0	14.0	31.0	70.0	67.0	28.0	17.0	33.0	[illegible]	17.0	18.0	16.0	347.0
1903	10.0	13.0	45.0	77.0	100.0	110.0	86.0	27.0	22.0	22.0	22.0	18.0	552.0
1904	10.0	13.0	24.0	28.0	25.0	17.0	16.0	50.0	145.0	60.0	30.0	22.0	440.0
1905	12.0	17.0	55.0	80.0	110.0	110.0	54.0	36.0	22.0	24.0	28.0	22.0	570.0
1906	12.0	15.0	37.0	77.0	184.0	125.0	88.0	49.0	34.0	[illegible]	32.0	[illegible]	722.0
1907	14.0	17.0	49.0	180.0	130.0	190.0	205.0	75.0	48.0	38.0	30.0	23.0	999.0
1908	13.0	17.0	51.0	76.0	90.0	88.0	59.0	50.0	36.0	40.0	26.0	21.0	567.0
1909	12.0	16.0	42.0	135.0	[illegible]	190.0	75.0	50.0	53.0	40.0	26.0	22.0	911.0
1910	12.0	15.0	70.0	125.0	130.0	84.0	10.0	23.0	20.0	21.0	28.0	21.0	559.0
1911	20.0	17.0	48.0	76.0	110.0	97.0	100.0	46.0	47.0	60.0	62.0	32.0	705.0
1912	13.0	17.0	48.0	75.0	230.0	110.0	82.0	42.0	31.0	30.0	27.0	21.0	726.0
1913	12.0	16.0	39.0	75.0	90.0	80.0	40.0	17.0	23.0	38.0	29.0	22.0	481.0
1914	12.0	17.0	48.0	77.0	112.0	95.0	90.0	[illegible]	51.0	42.0	30.0	22.0	649.0
1915	12.0	16.0	45.0	83.0	98.0	210.0	75.0	47.0	32.0	30.0	26.0	23.0	697.0
1916	13.0	17.0	58.0	79.0	99.0	140.0	76.0	55.0	34.0	50.0	33.0	25.0	679.0
1917	13.0	17.0	43.0	77.0	96.0	108.0	92.0	35.0	25.0	24.0	27.0	22.0	579.0
1918	11.0	16.0	44.0	60.0	91.0	85.0	63.0	27.0	41.0	27.0	27.0	24.0	516.0
1919	12.0	16.0	47.0	80.0	100.0	92.0	90.0	49.0	30.0	34.0	29.0	25.0	[illegible]
1920	13.0	20.0	47.0	[illegible]	260.0	110.0	91.0	44.0	32.0	33.0	30.0	24.0	779.0
1921	13.0	17.0	49.0	63.0	95.0	105.0	82.0	59.0	42.0	32.0	29.0	25.0	611.0
1922	14.0	17.0	46.0	72.0	97.0	97.0	70.0	21.0	13.0	16.0	35.0	35.0	533.0
1923	13.0	17.0	41.0	70.0	100.0	95.0	58.0	48.0	47.0	47.0	34.0	26.0	596.0
1924	13.0	19.0	42.0	86.0	110.0	92.0	55.0	31.0	23.0	29.0	42.0	41.0	583.0
1925	30.0	17.0	46.0	76.0	80.0	48.0	58.0	57.0	32.0	38.0	30.0	26.0	538.0
1926	20.0	40.0	68.0	77.0	110.0	105.0	50.0	21.0	22.0	23.0	46.0	24.0	606.0
1927	12.0	17.0	44.0	77.0	150.0	93.0	165.0	43.0	50.0	47.0	32.0	26.0	756.0
1928	14.0	17.0	46.0	70.0	100.0	85.0	25.0	70.0	15.0	18.0	32.0	21.0	513.0
1929	13.0	16.0	43.0	73.0	97.0	91.0	52.0	60.0	50.0	45.0	32.0	26.0	598.0
1930	14.0	18.0	42.0	78.0	88.0	75.0	64.0	45.0	25.0	37.0	27.0	23.0	536.0
1931	12.0	17.0	43.0	63.0	83.0	38.0	24.0	23.0	36.0	37.0	26.0	23.0	425.0
1932	12.0	18.0	52.0	95.0	136.0	90.0	90.0	38.0	27.0	28.0	28.0	23.0	637.0
1933	12.0	16.0	42.0	57.0	90.0	92.0	47.0	30.0	27.0	26.0	25.0	23.0	437.0
1934	12.0	17.0	36.0	62.0	45.0	17.0	14.0	17.0	22.0	20.0	19.0	20.0	301.0
1935	12.0	16.0	29.0	55.0	92.0	98.0	72.0	50.0	37.0	34.0	29.0	23.0	547.0
46-year mean	12.7	16.7	45.0	83.8	109.8	94.4	65.1	38.6	33.3	32.8	29.8	23.6	585.6

TABLE 23.—*Estimated tributary inflow to the Middle Valley, Otowi Bridge to San Marcial*

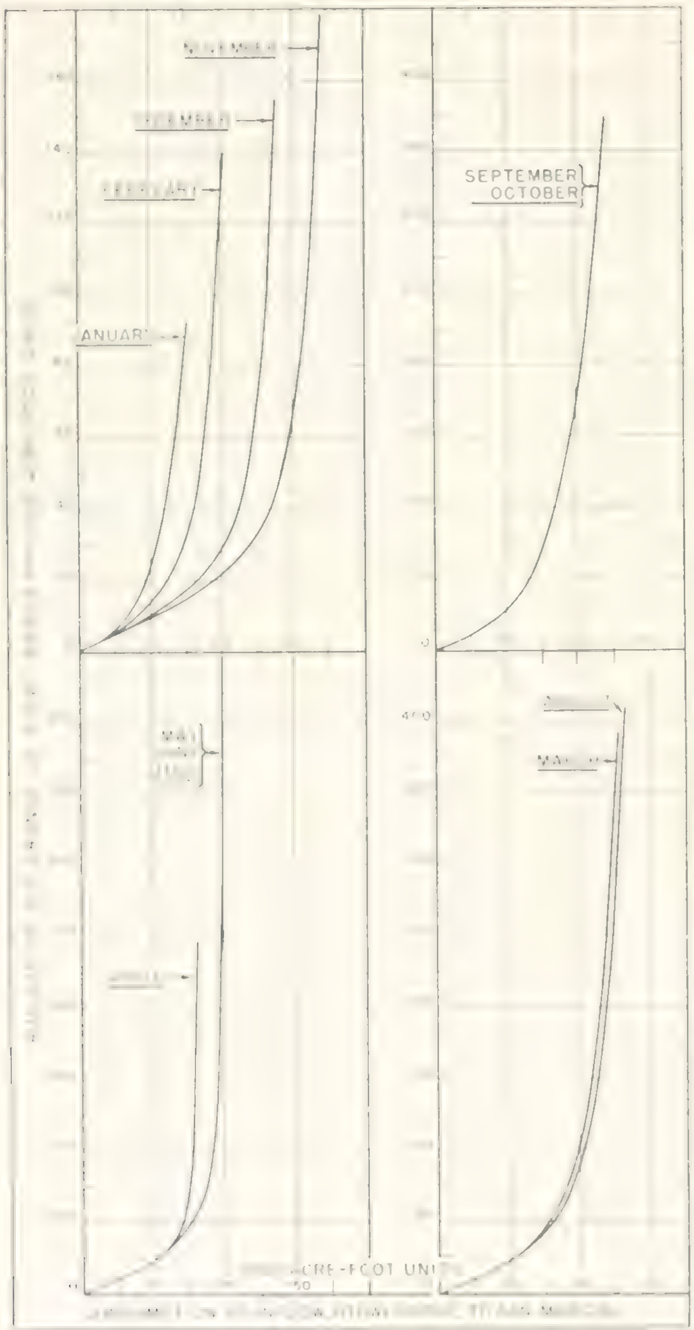
[Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1890	8.0	9.0	34.0	12.0	30.0	62.0	22.0	31.0	23.0	1.0	8.0	14.0	254.0
1891	7.0	36.0	104.0	68.0	400.0	130.0	45.0	16.0	84.0	37.0	6.0	5.0	938.0
1892	9.0	16.0	24.0	33.0	[illegible]	41.0	46.0	1.0	2.0	0	3.0	6.0	298.0
1893	14.0	12.0	17.0	10.0	47.0	7.0	3.0	0	0	0	0	13.0	123.0
1894	5.0	13.0	26.0	64.0	44.0	30.0	18.0	0	3.2	54.0	0	7.0	264.2
1895	10.0	37.0	91.7	21.0	34.0	52.0	125.0	[illegible]	13.0	11.9	5.7	17.2	[illegible]
1896	15.1	20.6	6.6	58.0	17.0	8.0	32.4	8.4	7.9	42.3	6.8	29.1	282.2
1897	[illegible]	9.2	22.0	15.0	158.0	100.0	44.7	6.7	105.5	195.0	136.1	143.8	937.8
1898	46.0	48.5	59.8	85.0	58.0	7.0	95.0	10.6	3.4	.1	6.6	7.2	427.2
1899	11.9	5.0	6.3	8.1	7.0	1.3	30.8	7.2	1.8	.1	6.5	6.6	92.6
1900	15.8	17.8	20.4	4.8	7.0	77.0	.8	0	17.5	.3	3.1	2.1	166.6
1901	6.6	5.0	6.5	7.3	33.0	50.2	61.5	56.7	31.1	12.8	13.6	10.7	297.0
1902	4.1	4.2	5.3	12.5	20.2	6.2	.3	48.0	9.5	.6	4.2	8.1	123.2
1903	4.1	10.2	16.6	5.0	11.0	61.0	26.8	3.5	1.1	.7	2.3	13.3	155.6
1904	5.9	7.7	8.8	.7	.8	0	11.4	14.0	41.7	270.0	32.4	28.4	421.8
1905	7.6	29.3	115.0	140.0	287.0	251.0	36.1	17.4	4.1	5.3	32.4	18.4	943.6
1906	12.5	19.7	47.9	65.0	30.0	25.0	51.0	9.2	5.5	12.8	31.8	58.1	368.5
1907	17.6	32.7	37.5	18.0	11.0	44.0	49.0	13.0	90.0	33.5	32.5	26.7	405.5
1908	13.6	17.0	20.4	50.0	45.0	26.5	48.0	48.7	.7	.8	20.9	28.4	320.0
1909	14.6	10.3	33.6	4.0	16.0	24.0	28.4	12.9	29.0	18.5	36.5	28.3	256.1
1910	35.9	25.7	14.0	10.0	13.0	17.1	.1	8.2	3.0	.6	3.1	11.9	142.6
1911	2.5	11.2	43.5	18.5	6.0	27.0	142.0	39.7	11.9	37.0	46.0	11.5	396.8
1912	14.7	18.6	30.7	54.0	31.0	46.0	79.0	11.8	.3	.8	16.3	13.5	316.7
1913	1.6	18.2	25.4	28.1	39.0	63.1	9.1	.4	2.1	21.2	14.9	11.7	234.8
1914	9.2	14.3	23.5	23.0	6.0	48.0	[illegible]	22.2	.8	32.2	17.2	25.6	332.0
1915	8.2	14.0	25.2	120.0	32.0	36.0	103.5	22.0	6.5	3.1	13.2	19.7	403.4
1916	16.7	14.5	28.0	47.0	36.0	21.0	23.2	20.8	2.7	47.0	26.3	18.3	301.5
1917	16.5	13.4	17.0	8.6	23.0	20.0	70.0	[illegible]	4.9	.2	4.1	15.2	196.4
1918	6.3	6.2	21.8	19.1	23.0	16.2	19.9	2.3	0	7.0	11.3	20.2	153.3
1919	10.7	17.8	36.4	80.0	17.0	58.0	200.0	41.9	.9	11.0	15.4	26.0	518.1
1920	15.8	29.7	45.4	72.0	76.0	268.0	83.0	23.2	.6	1.0	13.6	15.5	643.8
1921	12.9	14.4	28.8	35.1	52.0	82.0	180.0	25.0	9.2	10.5	16.9	26.7	493.5
1922	19.0	15.6	26.8	46.5	40.0	39.0	37.6	.3	0	.1	.1	5.5	[illegible]
1923	9.6	10.2	36.2	39.5	8.0	55.0	28.6	44.1	50.0	8.6	[illegible]	24.2	354.5
1924	24.4	35.7	58.4	125.0	34.0	22.0	49.6	7.0	2.3	.5	4.3	6.7	369.9
1925	1.3	4.7	7.8	23.2	14.9	3.6	[illegible]	3.5	16.4	3.9	8.6	13.0	111.5
1926	15.4	31.5	51.4	20.0	105.0	42.0	28.2	2.5	3.3	1.3	20.4	17.1	338.1

TABLE 23.—*Estimated tributary inflow to the Middle Valley, Otowi Bridge to San Marcial*—Continued

[Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1927	[illegible]	9.8	12.7	34.0	31.0	37.0	133.0	55.5	[illegible]	21.0	21.2	[illegible]	473.6
[illegible]	[illegible]	14.9	20.6	13.8	4.0	56.0	[illegible]	[illegible]	[illegible]	.9	[illegible]	18.1	210.4
1929	[illegible]	7.3	22.5	31.8	25.0	39.0	[illegible]	173.0	210.0	61.0	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	11.8	45.6	41.0	57.0	[illegible]	77.7	30.8	[illegible]	.6	3.9	19.0	[illegible]
[illegible]	[illegible]	[illegible]	28.5	44.8	51.8	4.6	10.4	7.3	37.0	29.6	16.1	24.4	[illegible]
[illegible]	16.5	19.4	20.2	3.0	30.0	6.0	103.0	57.2	7.9	9.7	11.4	19.7	308.0
[illegible]	[illegible]	16.1	30.0	11.8	7.5	150.0	38.3	37.7	16.0	11.7	17.3	28.5	[illegible]
[illegible]	[illegible]	[illegible]	18.8	21.4	6.0	.9	[illegible]	34.2	[illegible]	1.5	1.2	19.5	165.1
[illegible]	[illegible]	[illegible]	23.3	20.7	73.0	103.0	19.7	73.9	37.8	16.6	25.1	36.0	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	50.1	51.7	27.1	22.0	22.6	17.6	21.0	358.7



annual side inflow, 1890 to 1935, of 358,700 acre-feet. These data give a very poor correlation with available records of flow at gaging stations on tributary streams, but the latter are very incomplete and meager. A fair correlation is indicated with the mean annual water production as previously developed for the southern unit of the Middle section (see table 199 in Appendix B), after the latter is corrected for the irrigation consumption on the tributary streams. Many inconsistencies appear in a comparison by individual years.

In order to smooth the effect of annual irregularities and to bring out more clearly the relation between and general trend over the years of the total inflow, Otowi Bridge to San Marcial, its consumption and the residual flow at San Marcial, progressive 5-year weighted means of these quantities were computed and plotted in figure 18. The curve designated "available inflow" was made up from the sum of the Rio Grande flow at Otowi Bridge and the estimated side inflow as given by table 23. The "consumption of inflow" curve was derived from the figures of table 22, and the curve of "residual flow at San Marcial" from those of table 161 in Appendix A. No marked long-time trend in consumption of inflow is exhibited. Rather, it is indicated that little change in this consumption, except that due to variation in the water supply, has occurred since 1890.

Because of the uncertainty with respect to tributary inflow, past stream-flow depletion in the Middle Valley is, as previously indicated, highly indeterminate. The method employed herein to estimate it involves selections which are more or less a matter of individual judgment. Because of the unfortunate lack of basic data there is, however, no method of approaching this determination which does not rely to some extent on the judgment of the investigator. If the effect upon the Elephant Butte-Fort Quitman section of present and given future conditions of irrigation development in the San Luis and Middle sections is to be determined upon the basis of stream flow in the past, it is indispensable that some knowledge or estimate of past depletion be available so that the past San Marcial flows can be modified by the differentials between the past and present or future depletion. The estimate

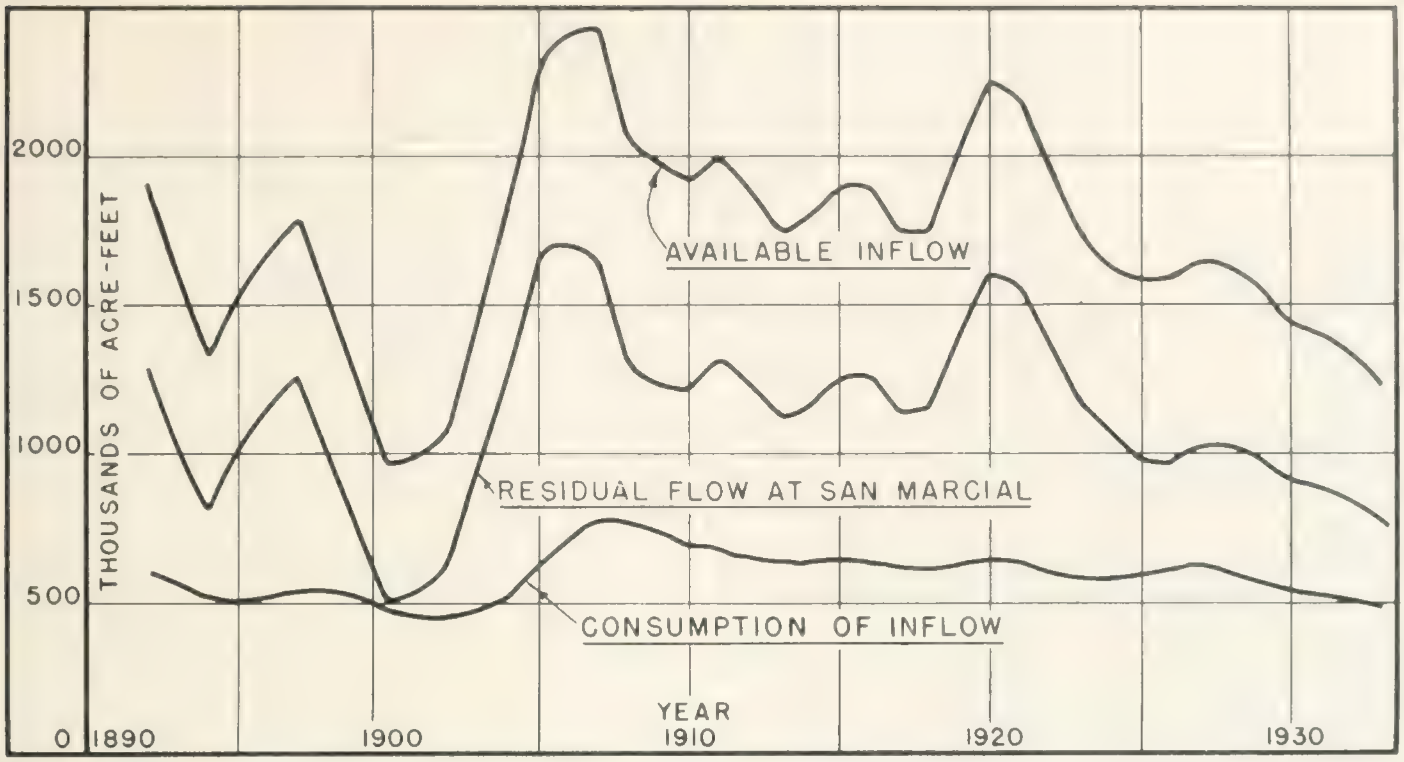


FIGURE 18.—Available inflow, consumption of inflow, and residual flow at San Marcial, Middle Rio Grande Valley, Otowi Bridge to San Marcial, 1890–1935. (Available inflow is Rio Grande flow at Otowi Bridge plus estimated side inflow, Otowi Bridge to San Marcial. Curves are plotted from progressive 5-year weighted means of annual data.)

herein of past depletion in the Middle Valley was derived to meet this particular requirement of analysis. Although subject to relatively wide variation in derivation because of the indeterminate character of available data, this estimate is believed to approach within reasonable limits the actual consumption of inflow which occurred, and to be adequate for purposes of analysis if, based thereon, a reasonably wide latitude is maintained in determining the sufficiency of water supplies or additional requirements for water. The estimate is not, however, considered to be sufficiently close, nor is it thought possible with available data to derive an estimate which would be sufficiently close, to permit of exact or even close deductions with respect, for example, to the effect on the regimen of the river of the works and operations of the Middle Rio Grande Conservancy District, or to the effect of certain conditions obtaining in particular years.

Deduced San Marcial Flow.—In the preceding derivations the San Marcial flow used was that published by the Geological Survey and given in table 161 in Appendix A. In a number of reports a question has been raised concerning the accuracy of portions of the San Marcial record. In order to check the record, at least for large discrepancies, a study was made to estimate the inflow to Elephant Butte Reservoir at San Marcial, using the records of reservoir storage, releases, evaporation, and rainfall available since January 1915. The records of releases and evaporation used are given in tables 187 and 123, respectively, in Appendix A. Monthly change in storage was computed from a compilation furnished by the Bureau of Reclamation showing storage on hand on the first day of each month. These storage figures, shown to the nearest thousand acre-feet in table 24, have been corrected for reductions in reservoir capacity due to accumulations of silt from September 1925 to December 1934, inclusive, in accordance with the silt survey of September 1925, and from January to December 1935, in accordance with the April 1935 survey.

Evaporation was computed by applying a correction factor of 0.687 to the Standard Weather Bureau class A pan record at Elephant Butte Dam covering the periods 1915 to 1925 and July 1933 to June 1936. This factor for reduction of pan to reservoir evaporation is derived from the Rohwer experiments as reported in Technical Bulletin No. 271, December 1931, of the Department of Agriculture. In averaging the pan records, those for the period January 1926 to June 1933 were not used since it was indicated that evaporation was then affected by shade from trees near the pan. The correction factor applied to the averaged pan records gave the monthly values for reservoir evaporation listed in table 25. Using a tabulation of mean monthly storage content furnished by the Bureau of Reclamation, the computed rates of evaporation were applied to the mean reservoir surface area for each month as determined from area capacity relations

TABLE 24.—*Storage in Elephant Butte Reservoir*

[illegible]

Year	January	February	March	April	May	June	July	August	September	October	November	December
[illegible]		9	[illegible]	[illegible]	[illegible]	152	[illegible]	515	[illegible]	375	[illegible]	358
[illegible]	[illegible]	[illegible]	406	[illegible]	[illegible]	[illegible]	[illegible]	795	[illegible]	[illegible]	[illegible]	942
[illegible]	[illegible]	818	752	676	[illegible]	769	995	[illegible]	848	731	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	728	[illegible]	447	458	424	351	[illegible]	[illegible]	190	187
[illegible]	[illegible]	[illegible]	[illegible]	206	533	934	[illegible]	1,112	1,079	[illegible]	[illegible]	[illegible]
[illegible]	1,041	[illegible]	1,120	1,119	1,145	1,640	[illegible]	2,058	[illegible]	1,819	1,751	1,744
[illegible]	1,729	1,753	1,732	1,707	1,628	1,694	2,077	2,091	2,081	1,972	1,877	1,830
[illegible]	[illegible]	1,840	1,811	1,771	[illegible]	1,880	1,900	1,852	1,697	1,619	1,487	1,461
[illegible]	1,441	1,461	1,450	1,427	[illegible]	1,504	1,522	1,382	1,365	1,380	1,418	1,507
[illegible]	[illegible]	1,596	1,593	1,573	1,826	2,205	2,141	2,031	1,842	1,760	1,719	[illegible]
1925	[illegible]	[illegible]	1,645	[illegible]	[illegible]	1,435	1,302	1,170	1,088	1,052	1,073	[illegible]
1926	[illegible]	[illegible]	1,033	[illegible]	1,015	1,331	1,413	1,326	1,196	1,115	1,098	[illegible]
[illegible]	1,098	1,125	[illegible]	1,081	1,089	[illegible]	1,273	1,267	[illegible]	1,286	1,347	1,368
[illegible]	1,387	1,410	1,418	1,376	1,273	1,424	1,379	1,221	1,104	1,007	[illegible]	971
[illegible]	[illegible]	[illegible]	[illegible]	962	901	1,079	1,070	[illegible]	1,155	1,360	1,461	[illegible]
[illegible]	1,541	1,568	1,575	[illegible]	1,605	1,599	1,520	1,471	1,384	[illegible]	1,257	[illegible]
[illegible]	1,273	1,307	1,336	1,291	1,241	1,217	1,091	[illegible]	[illegible]	[illegible]	892	[illegible]
[illegible]	924	[illegible]	1,002	1,036	1,172	1,517	1,596	1,578	1,487	1,389	1,381	1,381
[illegible]	[illegible]	[illegible]	1,434	[illegible]	1,273	1,213	1,392	1,294	1,181	1,119	1,108	1,125
1934	[illegible]	[illegible]	1,151	1,096	[illegible]	[illegible]	767	635	518	[illegible]	[illegible]	493
[illegible]	[illegible]	506	528	[illegible]	[illegible]	496	[illegible]	580	[illegible]	[illegible]	[illegible]	633

[illegible]

[illegible] December 1934, inclusive, corrections have been made in accordance with the silt survey of September 1925 and from January to December 1935 in accordance with the survey of April 1935.

shown by the original survey for the period January 1915 to August 1925, by the 1925 silt survey for the period September 1925 to December 1934, and by the 1935 silt survey for the period January to December 1935, to derive the total monthly evaporation in acre-feet.

TABLE 25.—*Evaporation from Elephant Butte Reservoir*

[illegible]

Month	Evaporation	Month	Evaporation
January	[illegible]	August	0.64
February	[illegible]	September	.54
March	[illegible]	October	[illegible]
April	[illegible]	November	.26
May	[illegible]	December	.16
June	[illegible]		
July	[illegible]	Total	6.00

[illegible] 1936.

Rainfall accretion to the reservoir was determined similarly by applying to its mean water-surface area for each month the corresponding monthly precipitation at the Elephant Butte Dam station.

In Appendix B the tributary run-off of the San Marcial-Elephant Butte unit is developed from precipitation data by comparison to the precipitation-run-off relations found for the Elephant Butte-Leasburg and Leasburg-El Paso units. The run-off so derived, shown in column 4 of table 202, less the flow of Alamosa River which is used in irrigation, was taken in the present study as representing the arroyo inflow to Elephant Butte Reservoir. Monthly distribution of the annual inflows was based upon the corresponding distribution of precipitation at the stations used for this unit.

An estimate of reservoir seepage was made by comparing the total visible surface inflow as given by the data of storage changes, releases, evaporation, rainfall, and arroyo inflow to the measured inflow at San Marcial for the period January 1926 to May 1934. With the exception of 1 month in 1929 and 3 months in 1932, the recorded San Marcial flow appeared to be more uniformly consistent with the estimated inflows as derived by this study and hence to be a comparatively good record. The reservoir content at the beginning and end of this period was practically the same, so that the effect of bank storage and release was eliminated. For the 101 months of the period, the total difference, attributable to seepage, amounted to 559,000 acre-feet, or an average of 5,540 acre-feet per month. A seepage correction of 6,000 acre-feet per month, April to September, and 5,000 acre-feet per month, October to March, or a total of 66,000 acre-feet per year, was applied throughout the period of record. For the years when the reservoir first filled this correction is probably too small but no attempt was made to allow for this priming.

The monthly inflow at San Marcial, 1915 to 1935, as estimated by this study, is shown in table 26, and is to be compared with the recorded inflow as given in table 161 in Appendix A. A comparison of the annual inflow as estimated and as recorded is shown in table 27. These comparisons reveal wide discrepancies in certain months, particularly during the flood season. Small differences may be attributed to incorrect estimates of arroyo inflow, to variation in monthly rate of seepage including bank storage and release, or to small errors in the measurements of one or more of the various records involved. Analysis of the major discrepancies indicates that measurements of inflow at San Marcial

TABLE 26.—*Estimated inflow to Elephant Butte Reservoir at San Marcial*

[Computed from data of storage changes, release, evaporation, rainfall, and estimated seepage and arroyo inflow, for comparison with recorded San Marcial flow, [illegible]. Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1915	14	13	62	[illegible]	403	301	63	28	0	15	21	32	1,214
1916	53	[illegible]	164	223	156	198	[illegible]	79	19	209	[illegible]	1	1,639
1917	[illegible]	30	45	103	219	380	173	13	2	[illegible]	15	31	[illegible]
1918	[illegible]	26	39	51	119	74	27	6	2	24	24	42	[illegible]
1919	41	34	96	[illegible]	541	171	231	69	[illegible]	22	36	53	[illegible]
1920	47	84	77	134	653	597	111	28	0	2	[illegible]	32	1,807
1921	37	28	80	28	201	[illegible]	146	133	[illegible]	[illegible]	25	32	[illegible]
1922	37	39	52	68	329	[illegible]	14	4	53	[illegible]	15	25	[illegible]
1923	41	34	47	[illegible]	[illegible]	180	11	[illegible]	110	[illegible]	109	74	1,150
1924	42	[illegible]	62	400	[illegible]	119	30	[illegible]	28	13	[illegible]	[illegible]	[illegible]
1925	[illegible]	38	45	102	58	19	7	[illegible]	26	12	[illegible]	18	414
1926	44	42	71	137	412	240	24	0	[illegible]	4	8	[illegible]	1,024
1927	41	44	36	142	322	165	150	[illegible]	181	111	50	[illegible]	1,343
1928	43	[illegible]	47	44	262	111	0	[illegible]	7	7	[illegible]	[illegible]	[illegible]
1929	[illegible]	31	[illegible]	78	[illegible]	132	13	[illegible]	279	[illegible]	[illegible]	52	1,328
1930	[illegible]	51	68	191	122	64	88	[illegible]	0	4	18	37	726
1931	13	56	45	51	100	19	12	8	60	[illegible]	22	18	[illegible]
1932	47	72	111	268	475	[illegible]	135	2	3	17	31	33	1,480
1933	46	44	51	12	72	300	46	33	42	18	42	[illegible]	739
1934	46	[illegible]	29	29	17	12	16	26	57	10	13	[illegible]	305
1935	42	37	32	28	150	305	50	110	64	38	47	51	[illegible]

during flood stages are probably more inaccurate than measurements of reservoir release or content, and that the former measurements are usually high. These large differences are most frequent in the years 1919 to 1924 and in 1932. In 1921 they are to be noted in almost every month. Comparison of the recorded and deduced inflows for the months when it appears probable that the former may be considerably in error is given in table 28.

There are indications in some months of errors also in the records other than those at San Marcial. The monthly differences which show these are, with few exceptions, under 10,000 acre-feet. In some cases a negative San Marcial inflow is shown, and in others a small inflow is shown when the recorded flow is zero. Comparison of the recorded and deduced inflows for the months when differences exceeding 10,000 acre-feet indicate the probability of errors in records other than those at San Marcial is given in table 29.

TABLE 27.—*Comparison of estimated and recorded inflow to Elephant Butte Reservoir at San Marcial*

[Estimated inflow derived from data of storage changes, releases, evaporation, rainfall, and estimated seepage and arroyo inflow. Unit 1,000 acre-feet]

Year	Recorded inflow	Estimated inflow	Difference
1915	1,354	1,214	−140
1916	1,649	1,639	−10
1917	1,055	1,126	71
1918	411	487	+76
1919	1,579	1,608	+29
1920	2,222	1,807	−415
1921	1,625	1,281	−344
1922	963	903	−60
1923	1,224	1,150	−74
1924	1,438	1,349	−89
1925	419	414	−5
1926	1,047	1,024	−23
1927	1,349	1,343	[illegible]
1928	591	612	+21
1929	1,465	1,328	−137
1930	731	726	−5
1931	490	527	+37
1932	1,400	1,480	+80
1933	716	739	+23
1934	244	305	+61
1935	1,030	954	−76
Mean	1,095	1,048	−47

It is difficult from this study to point out specific months or periods when the difference between recorded

TABLE 28.—*Comparison of deduced and recorded flow at San Marcial for months when recorded flow is indicated to be in error*

[Unit 1,000 acre-feet]

Year and month	Recorded flow	Deduced flow	Departure of recorded from deduced flow
[illegible]			
May	487	541	−54
1920			
June	863	597	+266
July	176	111	+65
			+331
1921			
February	44	28	+16
April	44	28	+16
May	216	201	+15
June	649	532	+117
July	206	146	+60
August	158	133	+25
September	62	33	+29
October	26	6	+20
November	38	25	+13
December	55	32	+23
			+334
[illegible]			
January	58	37	+21
February	49	39	+10
March	57	52	+5
April	82	68	+14
May	344	329	+15
June	311	267	+44
July	50	14	+36
			+145
[illegible]			
June	221	180	+41
[illegible]			
June	134	119	+15
July	50	[illegible]	+20
			[illegible]
[illegible]			
August	275	219	+56
[illegible]			
April	235	268	−33
May	431	475	−44
June	212	236	−24
			−101
Total	5,533	4,746	+787

TABLE 29.—*Comparison of deduced and recorded flow at San Marcial for months when records other than San Marcial are indicated to be in error*

[illegible]

[illegible]	[illegible] flow	[illegible]	[illegible] recorded from deduced flow
[illegible]			
[illegible]	[illegible]	−14	+21
[illegible]			
[illegible]	[illegible]	−12	+18
[illegible]			
[illegible]	0	53	−53
[illegible]	0	−57	+57
[illegible]	0	15	−15
[illegible]			
[illegible]	4	19	−15
[illegible]	40	−97	+137
[illegible]			
[illegible]	[illegible]	12	−12
[illegible]	0	16	−16
Total	57	−65	+122

and deduced San Marcial flows may be considered a definite reflection on the accuracy of the San Marcial record. It appears, however, that for the months and periods given in table 28 there is some justification for questioning the San Marcial record and for substituting, in these months and periods, the deduced flow.

Middle Valley Depletion and Tributary Inflow Using Deduced San Marcial Flow.—Following the procedure previously outlined for estimating the past consumption of inflow and the tributary inflow, Otowi Bridge to San Marcial, new values were derived using the deduced San Marcial flow for the months and periods given in table 28. The changes in the consumption and side inflow estimates are indicated in table 30. This shows a total increase in the consumption figures for the corrected periods of 194,000 acre-feet and a total reduction in the tributary inflow figures of 572,900 acre-feet. The correspondingly revised 46-year means for consumption and tributary inflow are given in table 31.

Comparison of the mean annual figures for consumption of inflow and for tributary inflow, Otowi Bridge to San Marcial, as derived by use of the recorded San Marcial flow (tables 22 and 23), with those obtained by use of the deduced flow for San Marcial (table 31) shows a difference of 1,200 acre-feet for the consumption means and 12,500 acre-feet for the tributary inflow means. The relative insignificance of these differences, coupled with the uncertainties entering into the derivation of both the consumption of inflow and the deduced San Marcial flow, appears to give little justification for using the latter or any of the deductions not based on the recorded San Marcial flow.

Correction of Past Flow at Otowi Bridge and San Marcial.—Since there is relatively little irrigation from Rio Grande between the Lobato and Otowi Bridge

TABLE 30.—*Estimated consumption of inflow and tributary inflow, Otowi Bridge to San Marcial, corrected for deduced San Marcial flow*

[illegible]

[illegible]	Estimated consumption of inflow using San Marcial flow			Estimated tributary inflow using San Marcial flow		
	As recorded	As deduced	Correction	As recorded	As deduced	Correction
[illegible]						
May	[illegible]	[illegible]	−1.0	17.0	[illegible]	+53.0
[illegible]						
June	110.0	[illegible]	+50.0	268.0	52.0	−216.0
[illegible]	91.0	[illegible]	+9.0	83.0	27.0	−56.0
			+59.0			−272.0
[illegible]						
February	17.0	23.0	+6.0	14.4	3.9	[illegible]
April	63.0	63.0	0	35.1	18.7	−16.4
May	95.0	95.0	0	52.0	47.0	−5.0
June	105.0	190.0	+85.0	82.0	[illegible]	−32.0
July	[illegible]	82.0	0	[illegible]	120.0	−60.0
August	[illegible]	72.0	+13.0	25.0	13.0	−12.0
September	42.0	70.0	+28.0	9.2	8.3	−.9
October	[illegible]	42.0	+10.0	[illegible]	.6	[illegible]
November	29.0	29.0	0	16.9	4.2	−12.7
December	25.0	28.0	+3.0	26.7	6.5	[illegible]
			+145.0			[illegible]
[illegible]						
January	14.0	18.0	+4.0	19.0	[illegible]	−17.5
February	17.0	17.0	0	15.6	5.8	−9.8
March	46.0	46.0	0	26.8	21.9	−4.9
April	72.0	72.0	0	46.5	33.0	−13.5
May	97.0	97.0	0	40.0	25.0	[illegible]
June	97.0	115.0	+18.0	39.0	13.0	−26.0
July	70.0	82.0	+12.0	37.6	14.0	[illegible]
			+34.0			−110.3
[illegible]						
June	95.0	[illegible]	0.0	[illegible]	14.0	−41.0
[illegible]						
June	92.0	95.0	+3.0	22.0	10.0	−12.0
July	55.0	55.0	0	49.6	[illegible]	−20.0
			+3.0			[illegible]
[illegible]						
August	60.0	60.0	0	173.0	117.0	−56.0
[illegible]						
April	95.0	80.0	−15.0	3.0	21.0	+18.0
May	136.0	99.0	−37.0	30.0	47.0	+17.0
June	90.0	96.0	+6.0	6.0	36.0	+30.0
			−46.0			+65.0
Total	[illegible]	[illegible]	+194.0	1,382.9	[illegible]	−572.9

TABLE 31.—*Estimated mean consumption of inflow and mean tributary inflow, Otowi Bridge to San Marcial, 1890–1935, using deduced San Marcial flow*

[illegible]

Month	[illegible]	
	Consumption of inflow	Tributary inflow
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	109,000	[illegible]
[illegible]	97,900	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
December	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

gaging stations and since the river is confined to a narrow canyon for much of the intervening distance, it was considered that corrections to past flow for present development in the San Luis section as applied to the Lobatos record should be applicable, without change, to the Otowi Bridge record. The corrections of table 17 were therefore applied to the Otowi Bridge run-off given by table 158 in Appendix A to derive the figures of table 32.

In order to carry the corrections for present development through to San Marcial, it became necessary to take into account the relation between Otowi Bridge flow and the Middle Valley consumption of inflow as previously developed and shown by the curves of figure 17. These curves were first entered with the recorded Otowi Bridge flow (table 158) and then with the corresponding Otowi Bridge flow corrected for present San Luis Valley development (table 32). The difference between the two curve values so obtained gave corrections which were applied to the Middle Valley consumption figures of table 22 to give those of table 33, "Estimated consumption of inflow to the Middle Valley, Otowi Bridge to San Marcial, under present irrigation development in San Luis Valley." In these new consumption values, adjustment was made where necessary to conform to the total available inflow; that is, the new Otowi Bridge flow plus side inflow. The corrections for San Luis Valley development given by table 17, less the corresponding change in Middle Valley consumption given by the difference between the values of tables 22 and 33, gave the corrections which were applied to the San Marcial record (table 161, Appendix A) to derive the figures of table 34, "Estimated run-off of Rio Grande at San Marcial, N. Mex., under present irrigation development in San Luis Valley."

Return Water

In the main river valleys of the upper basin a supply of considerable magnitude is water which, once diverted for irrigation, returns to the stream as direct drainage or as inflow from the ground-water basin. This "return water" has its source (1) in losses from canals or other conduits during conveyance of water from points of

TABLE 32.—*Estimated run-off of Rio Grande at Otowi Bridge, N. Mex., under present irrigation development in San Luis Valley*

[Drainage area 11,303 square miles.[1] Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in percent of mean
[illegible]	33.0	35.0	72.0	268.0	602.0	245.0	87.0	62.0	38.0	38.0	45.0	52.0	1,577.0	126.1
[illegible]	41.0	44.0	99.0	305.0	616.0	314.0	116.0	69.0	34.0	115.0	51.0	51.0	1,855.0	148.3
[illegible]	39.0	45.0	102.0	376.0	515.0	196.0	[illegible]	15.0	8.0	19.0	31.0	24.0	1,411.0	112.8
[illegible]	25.0	29.0	30.0	180.0	348.0	166.0	27.0	18.0	20.0	33.0	31.0	26.0	933.0	74.6
[illegible]	26.0	26.0	48.0	118.0	222.0	38.0	17.0	22.0	22.0	10.0	43.0	49.0	641.0	51.2
[illegible]	32.0	31.8	93.3	302.0	260.0	221.0	82.0	65.1	31.0	36.1	48.6	51.8	1,254.7	100.3
[illegible]	35.9	37.5	87.2	182.0	155.0	28.8	23.3	13.9	23.8	31.3	39.6	35.0	693.3	55.4
[illegible]	35.7	35.1	80.8	279.0	617.0	268.0	72.3	25.4	57.5	196.0	69.9	51.2	1,779.0	142.2
[illegible]	28.7	37.9	47.4	233.0	187.0	207.0	100.0	36.2	[illegible]	23.9	38.6	42.2	999.2	79.9
[illegible]	23.0	34.6	76.2	162.0	113.0	28.7	37.6	23.2	51.1	29.6	59.0	38.2	676.2	54.1
[illegible]	35.8	31.3	55.8	44.5	202.0	128.0	19.3	10.1	42.6	28.8	34.3	27.0	[illegible]	52.7
[illegible]	23.4	33.5	41.6	84.4	287.0	110.0	42.8	49.8	36.5	32.2	41.5	[illegible]	814.2	65.1
[illegible]	29.6	27.2	33.7	96.6	68.6	25.2	16.7	34.2	28.8	21.2	26.4	27.2	435.4	[illegible]
[illegible]	26.1	29.7	84.2	172.0	380.0	548.0	107.0	26.6	27.3	26.8	32.2	27.6	1,487.5	118.9
[illegible]	20.9	26.2	29.3	35.3	30.2	17.0	15.1	93.0	159.0	303.0	53.4	35.4	817.8	65.4
[illegible]	40.5	48.6	139.0	201.0	613.0	425.0	52.7	35.7	23.2	27.0	42.0	38.9	1,686.6	134.8
[illegible]	32.0	32.0	52.0	158.0	602.0	389.0	122.0	66.0	50.0	101.0	77.0	52.0	[illegible]	138.6
[illegible]	50.0	46.0	97.0	339.0	410.0	509.0	455.0	[illegible]	74.0	46.0	50.0	44.0	2,293.0	183.3
1908	47.0	52.0	96.0	136.0	202.0	130.0	54.0	74.0	35.0	31.0	32.0	32.0	921.0	73.6
[illegible]	36.0	37.0	55.0	211.0	179.0	365.0	86.7	75.8	145.0	53.2	29.1	62.5	1,635.3	130.8
[illegible]	[illegible]	33.3	183.0	258.0	351.0	116.0	13.0	20.1	20.0	21.0	37.8	36.3	1,125.9	90.0
[illegible]	43.7	[illegible]	[illegible]	147.0	408.0	277.0	273.0	53.5	48.3	478.0	128.0	90.5	2,080.1	[illegible]
[illegible]	43.6	[illegible]	91.7	120.0	[illegible]	426.0	118.0	45.0	33.3	28.2	31.3	27.5	1,687.4	134.9
[illegible]	35.8	[illegible]	41.9	124.0	[illegible]	87.0	40.8	17.8	26.8	41.9	50.3	62.2	[illegible]	[illegible]
[illegible]	45.9	47.8	87.4	156.0	321.0	178.0	132.0	89.0	56.3	82.3	49.0	34.4	1,279.1	102.3
[illegible]	34.0	42.0	69.0	218.0	424.0	439.0	89.5	58.2	32.4	31.9	34.4	36.7	1,509.1	120.7
1916	42.1	[illegible]	191.0	250.0	500.0	347.0	124.5	99.0	40.7	181.0	81.8	55.6	1,959.3	156.6
[illegible]	38.1	46.5	62.8	145.0	271.0	465.0	222.0	30.6	23.8	17.8	25.4	26.2	1,374.2	109.9
[illegible]	28.7	[illegible]	59.8	69.4	189.0	143.0	60.5	26.4	34.0	28.0	41.0	43.5	749.9	[illegible]
[illegible]	36.7	[illegible]	82.2	261.0	475.0	180.0	146.0	79.9	35.1	48.3	49.6	60.1	1,492.5	[illegible]
[illegible]	[illegible]	74.7	81.8	125.0	838.0	626.0	181.0	54.7	31.3	32.7	49.5	39.4	[illegible]	171.4
[illegible]	34.1	44.1	89.0	60.3	237.0	471.0	108.0	166.0	[illegible]	28.4	41.8	[illegible]	1,403.9	112.2
[illegible]	45.5	49.2	[illegible]	99.0	416.0	309.0	61.0	27.7	11.5	15.9	39.9	44.2	1,199.0	95.9
1923	42.3	[illegible]	59.8	89.4	424.0	227.0	71.2	62.0	102.0	116.0	91.5	77.0	1,408.1	[illegible]
[illegible]	[illegible]	46.5	42.5	305.0	599.0	205.0	56.4	30.2	22.6	[illegible]	34.5	50.4	1,463.2	117.0
[illegible]	48.1	45.1	73.6	[illegible]	124.0	63.0	54.7	68.8	47.6	81.1	60.7	67.6	881.3	70.5
[illegible]	46.8	36.6	58.6	159.0	428.0	315.0	51.0	[illegible]	21.6	25.9	31.5	[illegible]	1,235.4	[illegible]
[illegible]	[illegible]	34.1	67.7	175.0	461.0	224.0	139.0	50.3	167.0	127.0	78.1	63.1	1,619.4	129.5
[illegible]	49.7	48.1	65.1	[illegible]	322.0	113.0	24.7	24.6	15.3	21.1	36.6	[illegible]	838.3	67.0
[illegible]	38.7	44.3	72.5	118.0	[illegible]	176.0	69.6	162.0	139.0	104.0	58.0	46.4	1,374.5	109.9
[illegible]	48.2	59.1	53.6	215.0	153.0	116.6	62.6	63.3	25.9	39.7	39.1	39.1	915.2	73.2
[illegible]	[illegible]	43.4	50.1	69.3	124.0	49.5	22.6	22.6	62.0	76.0	43.7	53.5	653.3	[illegible]
[illegible]	41.2	64.6	129.0	327.0	539.0	266.0	143.0	49.5	29.3	[illegible]	34.2	37.6	1,693.5	135.4
1933	42.2	39.5	54.5	58.0	186.0	196.0	46.5	31.2	31.3	30.2	38.7	41.7	795.8	63.6
[illegible]	39.2	[illegible]	54.9	89.1	47.4	15.3	13.5	14.5	22.9	21.4	20.4	28.3	412.4	33.0
[illegible]	34.2	29.3	47.1	68.8	198.0	392.0	113.3	84.1	63.8	51.6	51.1	33.6	1,166.9	93.3
Mean	37.3	40.6	75.2	170.0	350.8	234.4	87.2	53.0	[illegible]	[illegible]	46.9	43.9	1,250.7	100.0
[illegible]	2.98	3.25	6.01	13.59	28.05	18.71	6.97	4.24	[illegible]	5.20	[illegible]	[illegible]	100.0	

[1] [illegible]

TABLE 33.—*Estimated consumption of inflow to the Middle Valley, Otowi Bridge to San Marcial, under present irrigation development in San Luis Valley*

[illegible]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
[illegible]	11.0	[illegible]	[illegible]	[illegible]	130.0	94.0	79.0	44.0	30.0	39.0	[illegible]	24.0	657.0
[illegible]	[illegible]	17.0	50.0	80.0	[illegible]	99.0	81.0	46.0	29.0	43.0	[illegible]	[illegible]	638.0
[illegible]	[illegible]	17.0	70.0	[illegible]	103.0	[illegible]	45.0	15.0	8.0	19.0	[illegible]	18.0	626.0
[illegible]	10.0	[illegible]	30.0	109.0	97.0	173.0	30.0	18.0	20.0	28.0	24.0	19.0	573.0
[illegible]	11.0	14.0	38.0	73.0	93.0	35.0	19.0	[illegible]	22.0	[illegible]	32.0	29.0	[illegible]
[illegible]	11.0	[illegible]	18.0	79.0	95.0	93.0	77.0	46.0	26.0	29.0	29.0	24.0	573.0
[illegible]	12.0	16.0	[illegible]	77.0	[illegible]	27.0	27.0	15.0	22.0	27.0	27.0	22.0	408.0
[illegible]	[illegible]	[illegible]	46.0	105.0	[illegible]	98.0	66.0	[illegible]	34.0	54.0	32.0	[illegible]	620.0
[illegible]	11.0	[illegible]	38.0	79.0	91.0	104.0	79.0	34.0	17.0	23.0	32.0	21.0	548.0
[illegible]	10.0	[illegible]	[illegible]	130.0	89.0	29.0	40.0	24.0	[illegible]	27.0	44.0	23.0	[illegible]
[illegible]	12.0	15.0	40.0	46.0	[illegible]	84.0	20.0	10.0	31.0	27.0	30.0	20.0	429.0
[illegible]	10.0	16.0	36.0	67.0	95.0	80.0	46.0	41.0	29.0	27.0	27.0	21.0	495.0
[illegible]	11.0	[illegible]	31.0	70.0	63.0	25.0	17.0	33.0	25.0	21.0	23.0	20.0	353.0
[illegible]	10.0	14.0	47.0	77.0	99.0	109.0	80.0	27.0	25.0	25.0	25.0	20.0	558.0
[illegible]	[illegible]	[illegible]	[illegible]	35.0	31.0	17.0	16.0	50.0	146.0	62.0	30.0	22.0	[illegible]
1905	[illegible]	17.0	53.0	80.0	110.0	109.0	53.0	34.0	22.0	25.0	29.0	22.0	566.0
[illegible]	[illegible]	15.0	40.0	76.0	183.0	121.0	[illegible]	45.0	33.0	43.0	32.0	26.0	710.0
[illegible]	[illegible]	17.0	48.0	179.0	128.0	188.0	205.0	[illegible]	42.0	33.0	29.0	23.0	977.0
1908	[illegible]	17.0	50.0	[illegible]	89.0	84.0	[illegible]	46.0	32.0	31.0	25.0	21.0	537.0
[illegible]	[illegible]	[illegible]	40.0	135.0	249.0	189.0	73.0	47.0	18.0	34.0	26.0	25.0	893.0
[illegible]	[illegible]	15.0	69.0	[illegible]	129.0	81.0	12.0	21.0	20.0	[illegible]	29.0	[illegible]	[illegible]
1911	[illegible]	[illegible]	18.0	[illegible]	110.0	95.0	98.0	42.0	33.0	64.0	62.0	33.0	696.0
1912	[illegible]	17.0	18.0	[illegible]	230.0	109.0	82.0	39.0	29.0	25.0	26.0	20.0	710.0
[illegible]	[illegible]	16.0	36.0	73.0	89.0	72.0	43.0	18.0	24.0	31.0	29.0	25.0	468.0
[illegible]	[illegible]	17.0	[illegible]	76.0	111.0	90.0	89.0	49.0	46.0	41.0	29.0	[illegible]	630.0
1915	[illegible]	16.0	44.0	83.0	98.0	210.0	74.0	44.0	28.0	27.0	26.0	23.0	685.0
[illegible]	[illegible]	17.0	58.0	[illegible]	99.0	140.0	83.0	51.0	31.0	51.0	[illegible]	25.0	678.0
1917	[illegible]	17.0	42.0	75.0	95.0	108.0	93.0	30.0	23.0	18.0	23.0	20.0	557.0
1918	[illegible]	[illegible]	42.0	58.0	91.0	86.0	60.0	27.0	34.0	25.0	27.0	[illegible]	499.0
1919	[illegible]	[illegible]	[illegible]	79.0	100.0	90.0	92.0	48.0	29.0	33.0	29.0	26.0	601.0
[illegible]	[illegible]	[illegible]	46.0	73.0	260.0	110.0	91.0	42.0	[illegible]	29.0	29.0	23.0	[illegible]
1921	[illegible]	[illegible]	48.0	57.0	94.0	103.0	82.0	57.0	39.0	25.0	28.0	25.0	[illegible]
[illegible]	[illegible]	[illegible]	46.0	70.0	97.0	96.0	61.0	27.0	14.0	16.0	36.0	35.0	528.0
[illegible]	[illegible]	17.0	[illegible]	[illegible]	101.0	93.0	66.0	44.0	45.0	45.0	34.0	26.0	593.0
[illegible]	[illegible]	[illegible]	36.0	84.0	109.0	[illegible]	56.0	30.0	[illegible]	27.0	38.0	41.0	566.0
[illegible]	[illegible]	17.0	45.0	75.0	81.0	60.0	63.0	56.0	33.0	40.0	30.0	27.0	557.0
1926	[illegible]	39.0	65.0	76.0	110.0	104.0	52.0	21.0	21.0	24.0	45.0	21.0	601.0
1927	[illegible]	[illegible]	44.0	77.0	150.0	93.0	159.0	42.0	51.0	47.0	32.0	27.0	750.0
1928	[illegible]	17.0	44.0	67.0	99.0	80.0	31.0	70.0	15.0	20.0	33.0	22.0	512.0
[illegible]	[illegible]	17.0	[illegible]	73.0	97.0	90.0	64.0	60.0	49.0	45.0	31.0	25.0	608.0
[illegible]	[illegible]	18.0	40.0	78.0	87.0	81.0	62.0	44.0	24.0	36.0	[illegible]	23.0	534.0
[illegible]	[illegible]	17.0	39.0	[illegible]	[illegible]	47.0	25.0	23.0	37.0	39.0	27.0	24.0	435.0
[illegible]	[illegible]	[illegible]	52.0	95.0	136.0	89.0	90.0	41.0	26.0	27.0	26.0	22.0	634.0
[illegible]	[illegible]	[illegible]	40.0	[illegible]	[illegible]	92.0	47.0	31.0	27.0	26.0	27.0	23.0	488.0
[illegible]	[illegible]	[illegible]	40.0	[illegible]	[illegible]	[illegible]	14.0	17.0	22.0	21.0	19.0	20.0	315.0
[illegible]	[illegible]	[illegible]	38.0	[illegible]	[illegible]	[illegible]	81.0	50.0	37.0	33.0	29.0	[illegible]	570.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31.8	[illegible]	[illegible]	580.2

TABLE 34.—*Estimated run-off of Rio Grande at San Marcial, N. Mex., under present irrigation development in San Luis Valley*

[illegible]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in [illegible]
[illegible]	[illegible]	29.0	62.0	161.0	502.0	213.0	30.0	49.0	31.0	[illegible]	25.0	42.0	1,174.0	113.9
[illegible]	[illegible]	[illegible]	153.0	293.0	896.0	345.0	80.0	39.0	89.0	109.0	24.0	38.0	2,165.0	210.0
[illegible]	[illegible]	44.0	[illegible]	210.0	[illegible]	145.0	42.0	1.0	2.0	0	6.0	12.0	1,083.0	105.0
[illegible]	[illegible]	26.0	17.0	81.0	[illegible]	0	0	0	[illegible]	5.0	5.0	20.0	481.0	46.6
[illegible]	[illegible]	25.0	36.0	[illegible]	[illegible]	33.0	16.0	0	3.2	52.0	11.0	27.0	505.2	49.0
[illegible]	31.0	52.8	[illegible]	[illegible]	[illegible]	[illegible]	130.0	158.0	18.0	19.0	25.0	45.0	[illegible]	120.2
[illegible]	[illegible]	42.0	45.8	[illegible]	114.0	9.8	28.7	7.3	9.7	46.6	19.4	42.1	[illegible]	55.0
[illegible]	[illegible]	28.3	[illegible]	189.0	670.0	270.0	51.0	6.1	119.0	337.0	174.0	169.0	[illegible]	203.3
[illegible]	[illegible]	70.4	69.2	239.0	154.0	[illegible]	116.0	12.8	3.7	1.0	13.2	25.4	[illegible]	85.2
[illegible]	[illegible]	23.6	23.5	40.1	31.0	1.0	28.4	6.4	1.9	2.7	21.5	21.8	226.8	22.0
[illegible]	[illegible]	34.1	[illegible]	3.3	[illegible]	121.0	0.1	0	[illegible]	2.1	7.4	9.1	421.0	41.1
[illegible]	[illegible]	[illegible]	12.1	33.7	225.0	80.2	58.3	[illegible]	38.6	18.0	[illegible]	21.2	625.2	[illegible]
[illegible]	[illegible]	17.4	8.0	39.1	[illegible]	6.4	0	49.2	13.3	0.8	7.6	15.3	[illegible]	19.9
[illegible]	[illegible]	25.9	53.8	100.0	292.0	500.0	53.8	3.1	3.1	[illegible]	9.5	20.9	[illegible]	105.2
[illegible]	16.8	19.9	[illegible]	1.0	0	0	10.5	57.0	54.7	511.0	55.8	41.8	777.6	75.4
[illegible]	36.1	[illegible]	201.0	261.0	[illegible]	567.0	35.8	[illegible]	5.3	7.3	45.4	[illegible]	2,064.2	200.2
[illegible]	33.5	[illegible]	59.9	147.0	449.0	290.0	91.0	30.2	22.5	70.8	76.8	84.1	1,391.5	135.0
[illegible]	[illegible]	61.7	86.5	178.0	293.0	365.0	299.0	111.0	122.0	[illegible]	[illegible]	47.7	1,721.5	167.0
[illegible]	47.6	52.0	[illegible]	[illegible]	158.0	[illegible]	48.0	76.7	3.7	0.8	[illegible]	39.4	704.0	[illegible]
[illegible]	39.6	31.3	[illegible]	80.0	216.0	200.0	[illegible]	41.7	126.0	37.7	[illegible]	65.8	[illegible]	[illegible]
[illegible]	[illegible]	44.0	128.0	144.0	235.0	[illegible]	1.1	7.3	3.0	[illegible]	11.9	26.2	713.5	69.2
1911	[illegible]	32.7	91.0	[illegible]	304.0	209.0	317.0	51.2	27.2	151.0	112.0	69.0	1,780.8	172.7
[illegible]	[illegible]	46.4	74.7	101.0	176.0	363.0	115.0	17.8	4.6	4.0	24.6	21.0	[illegible]	[illegible]
[illegible]	[illegible]	38.1	31.3	79.1	119.0	78.1	[illegible]	[illegible]	4.9	32.1	36.2	48.9	[illegible]	48.5
1914	[illegible]	45.1	63.9	104.0	[illegible]	136.0	153.0	62.2	[illegible]	[illegible]	37.2	38.0	981.1	[illegible]
[illegible]	40.2	40.0	[illegible]	255.0	[illegible]	265.0	[illegible]	36.2	10.9	8.0	[illegible]	33.4	1,227.6	119.1
[illegible]	[illegible]	44.1	[illegible]	249.0	437.0	228.0	64.7	68.8	12.4	177.0	[illegible]	48.9	1,582.8	[illegible]
1917	41.6	[illegible]	[illegible]	78.6	199.0	377.0	199.0	4.1	[illegible]	0	6.5	21.8	[illegible]	98.3
1918	24.0	18.8	[illegible]	[illegible]	[illegible]	[illegible]	20.4	1.7	0	10.0	25.3	39.7	404.2	39.2

[illegible]

TABLE 34.—*Estimated run-off of Rio Grande at San Marcial, N. Mex., under present irrigation development in San Luis Valley*—Con.

[illegible]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Annual run-off in percent of mean
1919	35.4	[illegible]	72.6	262.0	392.0	148.0	254.0	73.8	6.8	29.3	[illegible]	60.1	1,409.4	136.7
1920	19.3	84.4	81.2	121.0	654.0	784.0	173.0	35.9	2.9	4.7	31.1	[illegible]	2,059.4	199.7
1921	[illegible]	41.5	69.8	[illegible]	195.0	[illegible]	206.0	134.0	42.9	13.9	30.7	53.2	1,310.4	127.1
1922	51.5	17.8	57.9	[illegible]	359.0	252.0	37.6	[illegible]	[illegible]	[illegible]	4.0	11.7	900.0	87.3
1923	39.9	39.1	54.0	60.9	331.0	189.0	33.8	62.1	107.0	79.6	98.0	75.2	1,169.6	113.4
1924	56.0	64.1	64.9	[illegible]	[illegible]	[illegible]	50.0	7.2	[illegible]	[illegible]	0.8	16.1	1,267.0	122.9
1925	19.4	32.8	36.4	[illegible]	57.9	6.6	2.3	16.3	31.0	45.0	39.3	53.6	[illegible]	42.3
1926	42.2	29.1	45.0	[illegible]	[illegible]	253.0	27.2	2.6	3.9	3.2	6.9	33.4	971.5	94.2
1927	36.7	27.9	36.4	132.0	342.0	168.0	113.0	63.8	198.0	101.0	[illegible]	[illegible]	1,343.0	130.3
1928	18.6	46.0	41.7	31.2	227.0	89.0	0.6	9.4	5.0	1.0	7.3	29.8	536.6	52.0
1929	29.5	34.6	51.0	76.8	274.0	125.0	44.1	275.0	300.0	123.0	69.2	49.4	1,451.6	140.8
1930	44.8	52.9	59.2	178.0	123.0	76.5	78.3	50.1	4.8	4.3	16.0	35.1	723.0	70.1
1931	39.2	42.8	39.6	52.1	92.8	7.1	8.0	6.9	62.0	66.6	32.8	53.9	503.8	48.9
1932	45.7	66.0	97.2	235.0	433.0	183.0	157.0	65.7	11.2	15.8	22.6	35.3	1,367.5	132.6
1933	45.1	39.6	41.5	16.8	102.5	254.0	55.2	37.9	42.3	15.9	29.0	47.2	730.0	70.8
1934	46.9	45.3	33.7	42.5	4.4	0.2	[illegible]	31.7	[illegible]	1.9	2.6	27.8	262.5	25.5
1935	44.9	41.1	32.4	27.5	179.0	397.0	52.0	108.0	[illegible]	35.2	47.2	47.6	1,076.5	104.4
Mean	37.3	41.2	61.6	123.5	289.9	191.5	75.0	42.7	37.2	55.8	34.2	41.1	1,031.0	
Percent of annual	3.62	4.00	5.97	11.98	28.12	18.57	7.27	[illegible]	3.61	5.41	3.32	3.99	100.0	

diversion to points of use, (2) in surface drainage from the land after irrigation, and (3) in seepage to the underground basin. Beginning a few miles below Del Norte in San Luis Valley, Rio Grande receives varying amounts of return flow along many sections of its course to Fort Quitman, Tex. Return flow above Alamosa is available for rediversion and use in San Luis Valley. During the irrigation season the flow near Lobatos is largely return flow except for a few indivertible peaks which pass during short storm and flood periods. This flow is lost to San Luis Valley but becomes available for the Middle Valley section. In each of the subvalleys of the latter much of the return water reaches the river at the lower end and becomes available for rediversion in the succeeding valley. Below the San Acacia diversion at the head of Socorro Valley the return flow is lost for use in the Middle Valley but passes on to the Elephant Butte Reservoir and ultimate use in the Elephant Butte-Fort Quitman section. In the latter the return water of each subvalley becomes available to that next lower as far as the Tornillo heading of the Rio Grande Project. Below this, return water is available to the Hudspeth County Conservation and Reclamation District.

In estimating the water supply for the major units of the upper basin under given future conditions of irrigation development, the return water is an important consideration. In the following paragraphs, therefore, such data as are available with respect to its past and present volume and occurrence are presented.

The San Luis Section

In the analysis of return water in the San Luis Valley three units are considered: (1) the Rio Grande area from the Del Norte gage to Alamosa, (2) the Conejos area, and (3) the southwest area, excluding the Conejos area. In the first unit the return water may be taken as the residual quantity when the outflow at Alamosa is subtracted from the inflow at the Del Norte gage and appropriate allowance is made for intervening diversions. The return flow so derived will include that in definite channels, such as the Rio Grande drain from the north, the Bowen drain from the south, and Pinos and San Francisco Creeks, together with that coming in as ground-water seepage. Pinos and San Francisco Creeks are largely diverted, and accordingly their inflow to the river is itself chiefly return water. The necessary data for this derivation are available for the years 1928 to 1936, inclusive. Rio Grande flow at the Del Norte, Monte Vista, and Alamosa gages is given by tables in Appendix A. The diversions, 1928 to 1935, were compiled and furnished through the Colorado State Engineer. Those for 1936 were obtained under the Rio Grande joint investigation. The computation of the return flow in this unit, by months, for 1936, is shown in table 35. It will be noted that a division was made to give the return flow in two sections, Del Norte to Monte Vista and Monte Vista to Alamosa. The results similarly derived for the years 1928 to 1935, together with the 1936 data, are summarized in table 36. From this table it would appear that in the last 3 years there has been a marked increase in return flow between Del Norte and Alamosa. To a considerable extent it varies, as should be expected, with the amount of the diversions. For example, in 1931, a year of very low water supply, the total of the diversions was only 307,500 acre-feet, and the return flow dropped to 11,800 acre-feet, or 3.8 percent of the diversions, from a figure of 38,400 acre-feet in 1930, or 7.7 percent of the total diversions of 499,100 acre-feet in that year. However, in 1934, another very dry year, with total diversions of only 309,200 acre-feet, the return flow amounted to 37,700 acre-feet or 12.2 percent of the diversions. This, taken with the return

flow of 86,200 and 76,000 acre-feet for diversions of 670,900 and 479,600 acre-feet, respectively, in 1935 and 1936, is strongly indicative of a recent increase in return flow. The return figures of 1935 and 1936 represent, respectively, 12.8 and 15.8 percent of the diversions. Experience with respect to return water in general suggests that these percentages are very low and the explanation lies in the large diversions to the closed basin, from which there is little return to the river except by the one outlet drain of the Rio Grande Drainage District. Also Monte Vista and Empire Canals which divert near Monte Vista carry water far to the south so that return flow therefrom reaches Rio Grande below Alamosa. As shown by table 37, in the 9-year period, 1928 to 1936, the diversions from Rio Grande to the closed basin averaged 58.5 percent of the total diversions between the Del Norte and Alamosa gages.

The percentage of return flow in terms only of the diversions contributing to the return, may be closely approximated for the total river section from Del Norte gage to the mouth of Trinchera Creek as follows, using 1936 data:

(1) Inflow:	[illegible]
Rio Grande near Del Norte	472,000
Rio Grande drain (estimate based on past records, no data for 1936)	20,000
	492,000
(2) Outflow:	
Diversions to closed basin	278,000
Rio Grande at Alamosa less diversions below	60,000
Return flow below Alamosa from Rio Grande diversions (32,000 of table 40 reduced by ratio of Rio Grande diversions, 163,000, to total diversions, 265,000)	20,000
	358,000
(3) Diversions from Rio Grande:	[illegible]
Del Norte to Alamosa, excluding diversions to closed basin	202,000
Below Alamosa	9,000
	211,000
(4) Return flow (3) − (1) + (2)	77,000
Return in percent of diversions	36.5

This return of 36 percent of diversions conforms closely to the relative volume of return water as experienced in general.

In table 36 it will be noted that in the river section between the Del Norte and Monte Vista gages there are frequently, in many months of the year, losses of water rather than gains. This is explained by the fact that in the upper portion of this section, the river is traversing the apex of the Rio Grande alluvial fan. The material of this fan is coarse in texture and a considerable volume of water percolates from the stream channel to ground water. This is discussed in the section of Part II of this report which deals with ground water in San Luis Valley.

Based upon data for 1934, 1935, and 1936, the average monthly distribution of the return flow between Del Norte and Alamosa is given by table 38.

For estimate of the return water in the second San Luis Valley unit, the Conejos area, diversion data are available only for 1936 and the records for that year represent, in the main, water commissioners' reports that are based in many instances on estimates only. Using these data, the return water in the area served by the Conejos River and its tributaries was derived as shown in table 39. The return of 150,000 acre-feet, or 44.5 percent of the diversions, appears to be exceptionally high. It may be due, in part, to over estimates of the diversions but it is not, however, inconsistent with

TABLE 35.—*Return water between Del Norte and Alamosa gages, San Luis Valley, 1936*

[illegible]

Month	[illegible] near Del Norte	[illegible] Monte Vista	[illegible] (1) − (2)	[illegible] Del Norte to Monte Vista	[illegible] Del Norte [illegible] Vista (4) − (3)	[illegible] Grande at [illegible]	[illegible]	[illegible] Monte Vista to [illegible]	[illegible] Vista to Alamosa (8) − (7)	Total [illegible] (3) + (7)	[illegible] versions [illegible]	[illegible] (5) + (9)
	(1)	[illegible]	[illegible]	(4)	[illegible]	[illegible]	(7)	[illegible]	[illegible]	(10)	(11)	(12)
[illegible]	[illegible]	[illegible]	[illegible]			9.4	-0.1		[illegible]	[illegible]		0.1
[illegible]	[illegible]	11.1	−1.1	[illegible]	1.8	11.7	−.6		.6	−1.7		[illegible]
[illegible]	[illegible]	5.0	8.9	[illegible]	−.6	[illegible]	.1	[illegible]	4.5	9.0	12.9	[illegible]
[illegible]	67.3	17.3	[illegible]	[illegible]	1.4	[illegible]	[illegible]	[illegible]	5.7	64.5	71.6	[illegible]
[illegible]	[illegible]	42.3	98.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.7	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	21.0	68.1	71.3	3.2	2.9	[illegible]	[illegible]	7.8	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	33.1	34.6	1.5	[illegible]	[illegible]	7.8	3.9	37.0	42.1	5.4
[illegible]	[illegible]	[illegible]	32.2	38.2	6.0	[illegible]	[illegible]	[illegible]	[illegible]	34.1	46.1	12.0
[illegible]	[illegible]	[illegible]	23.2	[illegible]	4.9	[illegible]	[illegible]	[illegible]	4.3	25.6	[illegible]	9.2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.6	1.8	[illegible]	3.3	13.5	21.0	[illegible]
[illegible]	[illegible]	11.7	.7	[illegible]	.8	10.9	.8	[illegible]	1.3	1.5	3.6	2.1
[illegible]	[illegible]	[illegible]	[illegible]		1.8	12.2	[illegible]	[illegible]	.7	[illegible]	[illegible]	2.5
Total	[illegible]	[illegible]	[illegible]	[illegible]	31.1	[illegible]	79.7	124.6	41.9	103.6	[illegible]	76.0

Table 36.—*Return water between Del Norte and Alamosa gages, San Luis Valley, 1928–36*

(Unit 1,000 acre-feet)

	January	February	March	April	May	June	July	August	September	October	November	December	Total
1928													
Rio Grande near Del Norte	18.1	17.3	22.4	[illegible]	168.0	165.0	108.0	48.8	25.0	22.1	17.9	15.1	676.7
Rio Grande at Alamosa	17.8	17.3	23.1	12.7	28.9	[illegible]	3.1	2.2	1.3	1.4	10.1	11.7	152.9
Diversions Del Norte to Alamosa				31.4	[illegible]	[illegible]	105.3	54.6	30.6	26.1	6.0		529.7
Return flow—Del Norte to Monte Vista				[illegible]	−7.6	−12.2	−8.5	.6	1.8	−.3	−4.0		¹ −36.0
Return flow—Monte Vista to Alamosa				.9	.6	14.1	8.9	7.4	5.1	5.7	2.2		¹ 44.9
Return flow—Del Norte to Alamosa	−.3	0	.7	−4.9	−7.0	1.9	.4	8.0	6.9	5.4	−1.8	−3.4	[illegible]
1929													
Rio Grande near Del Norte	13.8	12.2	16.0	[illegible]	[illegible]	[illegible]	117.0	104.0	82.7	57.7	23.4	14.1	897.5
Rio Grande at Alamosa	11.6	11.1	16.4	14.8	18.2	35.8	[illegible]	50.1	[illegible]	40.6	29.2	19.8	[illegible]
Diversions Del Norte to Alamosa				47.0	172.2	178.2	128.4	73.8	30.5	² 4.2			[illegible]
Return flow—Del Norte to Monte Vista				3.5	−3.9	−8.9	2.7	12.2	[illegible]				[illegible]
Return flow—Monte Vista to Alamosa				7.7	8.3	[illegible]	12.6	7.7	1.4				[illegible]
Return flow—Del Norte to Alamosa	−2.2	−1.1	.4	11.2	[illegible]	−6.0	15.3	19.9	7.2	[illegible]	5.8	5.7	³ 47.7
1930													
Rio Grande near Del Norte	12.3	12.2	[illegible]	[illegible]	108.0	140.0	75.6	[illegible]	23.6	[illegible]	12.7	12.1	[illegible]
Rio Grande at Alamosa	12.9	17.8	14.6	7.6	5.2	3.3	7.6	3.5	1.0	1.4	7.7	8.3	[illegible]
Diversions Del Norte to Alamosa				39.4	105.3	143.2	78.2	68.1	29.4	29.9	5.6		499.1
Return flow—Del Norte to Monte Vista				−10.4	0	−.9	3.9	7.1	2.8	3.0	[illegible]		¹ 6.7
Return flow—Monte Vista to Alamosa				.8	2.5	7.4	6.3	[illegible]	4.0	3.8	−.6		[illegible]
Return flow—Del Norte to Alamosa	.6	5.6	−.8	−9.6	2.5	[illegible]	10.2	13.0	6.8	6.8	[illegible]	[illegible]	38.4
1931													
Rio Grande near Del Norte	8.3	9.3	12.3	28.2	73.8	99.4	35.4	18.7	23.1	30.4	12.2	10.2	361.3
Rio Grande at Alamosa	7.7	12.5	16.9	2.4	1.7	3.3	2.9	1.5	1.2	.9	3.6	11.0	65.6
Diversions Del Norte to Alamosa			1.5	[illegible]	73.0	97.0	40.8	22.1	27.3	16.3			[illegible]
Return flow—Del Norte to Monte Vista				−1.5	−3.5	−5.7	1.5	.5	1.4	−14.1	−6.7		¹ −28.1
Return flow—Monte Vista to Alamosa				5.2	4.4	6.6	6.8	4.4	[illegible]	.9	−1.9		¹ 30.4
Return flow—Del Norte to Alamosa	−.6	3.2	6.1	3.7	.9	.9	8.3	4.9	5.4	−13.2	−8.6	[illegible]	11.8
1932													
Rio Grande near Del Norte	11.4	11.3	16.5	66.6	[illegible]	236.0	146.0	106.0	30.6	26.3	[illegible]	[illegible]	[illegible]
Rio Grande at Alamosa	10.5	12.5	18.3	3.3	24.8	63.7	24.1	2.5	1.9	[illegible]	[illegible]	15.1	190.1
Diversions Del Norte to Alamosa				61.1	187.9	177.2	128.6	[illegible]	34.5	25.9			716.1
Return flow—Del Norte to Monte Vista			−4.8	−6.2	−8.7	−6.9	−10.0	−10.7	1.4	−.4	1.1		[illegible]
Return flow—Monte Vista to Alamosa			6.6	4.0	7.4	11.8	16.7	8.1	4.4	1.9	−.5		[illegible]
Return flow—Del Norte to Alamosa	−.9	1.2	1.8	−2.2	−1.3	4.9	6.7	[illegible]	5.8	1.5	.6	[illegible]	21.1
1933													
Rio Grande near Del Norte	10.2	8.6	14.4	23.6	81.2	169.0	79.3	39.4	27.1	24.2	14.7	12.9	504.6
Rio Grande at Alamosa	12.3	9.7	10.1	.7	2.0	7.0	2.7	2.3	1.3	1.0	4.2	13.4	66.7
Diversions Del Norte to Alamosa				24.4	78.4	172.6	80.5	45.1	31.2	27.5			459.7
Return flow—Del Norte to Monte Vista				−2.0	−2.6	4.4	−3.4	2.7	2.5	1.2	−4.6		¹ −1.8
Return flow—Monte Vista to Alamosa				3.5	1.8	6.2	7.3	5.3	2.9	3.1	−5.9		[illegible]
Return flow—Del Norte to Alamosa	2.1	1.1	−4.3	1.5	−.8	10.6	3.9	8.0	5.4	4.3	−10.5	[illegible]	21.8
1934													
Rio Grande near Del Norte	13.2	11.1	15.1	67.2	103.0	28.3	14.7	15.9	17.9	14.4	11.3	8.3	320.4
Rio Grande at Alamosa	10.7	13.1	4.5	1.2	2.2	3.0	1.8	1.7	1.0	[illegible]	.9	8.2	48.9
Diversions Del Norte to Alamosa			9.8	70.5	108.3	33.1	17.4	19.4	20.0	21.1	9.6		309.2
Return flow—Del Norte to Monte Vista		−3.3	−4.0	2.0	.2	1.5	.8	1.2	0	.6	−1.9	[illegible]	⁵ −0.3
Return flow—Monte Vista to Alamosa		5.3	3.2	2.5	7.3	6.3	3.7	4.0	3.1	6.7	1.1	−2.7	⁵ 40.5
Return flow—Del Norte to Alamosa	−2.5	2.0	−.8	4.5	7.5	7.8	4.5	5.2	3.1	7.3	−.8	−.1	37.7
1935													
Rio Grande near Del Norte	8.5	9.1	15.3	37.1	81.9	263.0	128.0	72.2	27.9	19.5	12.7	8.3	683.5
Rio Grande at Alamosa	7.3	[illegible]	.9	.9	3.2	50.0	6.5	1.6	1.5	3.1	5.8	11.1	98.8
Diversions Del Norte to Alamosa		4.8	12.8	36.5	72.7	238.4	150.2	82.7	36.2	23.8	12.8		670.9
Return flow—Del Norte to Monte Vista	2.9	−.6	−5.5	−3.0	−12.8	9.6	12.1	4.9	5.1	1.8	[illegible]	.9	14.7
Return flow—Monte Vista to Alamosa	−4.1	3.2	3.9	[illegible]	6.8	15.8	16.6	7.2	4.7	5.6	[illegible]	1.9	[illegible]
Return flow—Del Norte to Alamosa	−1.2	2.6	−1.6	.3	−6.0	25.4	28.7	12.1	9.8	7.4	5.9	2.8	86.2
1936													
Rio Grande near Del Norte	9.3	10.0	13.9	67.3	141.2	89.1	39.6	37.6	27.1	15.1	12.4	9.7	472.3
Rio Grande at Alamosa	9.4	11.7	4.9	2.8	5.0	2.9	2.6	3.2	1.5	1.6	10.9	12.2	68.7
Diversions Del Norte to Alamosa		7	12.9	71.6	149.0	97.2	42.4	46.4	34.8	21.0	3.6		[illegible]
Return flow—Del Norte to Monte Vista	0	1.8	−.6	1.4	6.1	3.2	1.5	6.0	4.9	4.2	.8	1.8	31.1
Return flow—Monte Vista to Alamosa	.1	.6	4.5	5.7	6.7	7.8	3.9	6.0	4.3	3.3	1.3	.7	[illegible]
Return flow—Del Norte to Alamosa	.1	2.4	3.9	7.1	12.8	11.0	5.4	12.0	9.2	7.5	2.1	2.5	76.0

¹ April to November inclusive, only.
² October diversions are incomplete.
³ April to September inclusive, only.
⁴ March to November inclusive, only.
⁵ February to December, inclusive.

the relative degree of return to be anticipated under the conditions of "wild flooding" which prevail in this area during the short period of the spring run-off.

For the third unit, the southwest area exclusive of the Conejos area, the return-water estimate is limited to 1936 for the same reason as in the case of the Conejos area. Here, again, the available diversion records are largely those of the water commissioners. This unit comprises the area south and west of Rio Grande served by southern diversions from the river between Del Norte and Alamosa and by Rock, Alamosa, and La Jara Creeks. As shown by table 40, the return flow of this unit in 1936 is estimated to have been 31,600 acre-feet or 12 percent of the diversions.

TABLE 37.—*Rio Grande diversions to the closed basin, San Luis Valley*

[illegible]

Item	1928	1929	1930	1931	1932	1933	1934	1935	1936	Mean
[illegible] Del Norte and Alamosa gages	[illegible]	634.3	[illegible]	307.5	716.1	459.7	309.2	[illegible]	479.6	511.8
[illegible]	330.9	369.7	[illegible]	150.0	142.4	275.5	144.6	113.3	278.2	300.0
[illegible]	62	58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 38.—*Monthly distribution of return water between Del Norte and Alamosa gages, San Luis Valley*

Month	[illegible] in percent of total annual [illegible]	[illegible]	Return water in percent of total annual return
January	[1]−1.8	July	19.3
February	3.5	August	[illegible]
[illegible]	0.8	[illegible]	11.0
April	[illegible]	October	11.1
May	[illegible]	November	3.6
[illegible]	22.[illegible]	[illegible]	2.6

[1] Loss.

TABLE 39.—*Return water in the Conejos area, San Luis Valley, 1936*

[illegible]

Month	Conejos River near [illegible] (1)	Los Pinos River near Ortiz (2)	[illegible] River at Ortiz (3)	Total inflow [illegible] (4)	Conejos River near [illegible] (5)	La Jara Drain (6)	Total outflow (5)+(6) (7)	[illegible] (4)−(7) (8)	[illegible] below gages (9)	Return flow (9)−(8) (10)
[illegible]	[illegible]	[illegible]	[illegible]	3.2	4.0	[illegible]	[illegible]	[illegible]		[illegible]
February	2.5	[1]1.0	[1].3	3.8	[illegible]	[illegible]	[illegible]	−.8		[illegible]
March	3.9	[illegible]	[illegible]	[illegible]	3.8	[2]	3.8	2.1	8.6	[illegible]
April	47.6	36.3	15.2	99.1	54.3	[2]	54.3	44.8	52.0	7.2
May	87.9	32.4	4.[illegible]	[illegible]	65.2	0.2	65.4	58.9	125.7	[illegible]
June	31.3	8.4	.3	43.0	4.9	.5	5.4	37.6	77.6	40.0
July	8.8	2.3	.4	11.[illegible]	.2	.2	.4	11.1	[illegible]	[illegible]
August	13.3	2.9	.9	17.1	2.8	.4	3.2	13.9	20.8	[illegible]
September	9.9	2.0	.2	12.1	2.4	.5	2.9	9.2	11.3	[illegible]
October	9.4	3.3	.5	13.2	5.4	[illegible]	6.0	7.2	[illegible]	5.7
November	[illegible]	3.0	.9	11.5	7.1	.6	7.7	3.8	6.8	3.0
December	[illegible]	[1]1.7	[1].4	6.2	5.4	[2]	[illegible]	.8		[illegible]
Total	[illegible]	[illegible]	[illegible]	350.9	160.1	3.0	163.1	187.8	337.8	150.0

[1] Estimated. [2] No record.

[illegible]

TABLE 40.—*Return water in the [illegible] area exclusive of the Conejos area, San Luis Valley, [illegible]*

[illegible]

Month	[illegible] to the area from the Rio Grande (1)	[illegible] Creek near Monte Vista (2)	[illegible] Creek [illegible] Terrace Reservoir (3)	La Jara Creek near Capulin (4)	Rio Grande at Alamosa (5)	La Jara Drain (6)	Total [illegible] (1) to (6) inclusive (7)	[illegible] Rio Grande above Trinchera Creek (8)	Difference (7)−(8) (9)	Diversions (10)	Return flow (10)−(9) (11)
[illegible]		[illegible]	2.1	[illegible]	[illegible]	[2]	11.8	[illegible]	2.4		−2.4
February		[1].2	1.9	[illegible]	11.7	[illegible]	14.0	[1]12.7	1.3		−1.3
March	5.4	[1].2	1.9	[illegible]	4.9	[illegible]	12.6	[1]10.1	2.5	7.3	[illegible]
April	[illegible]	[1]1.3	13.2	[1]1.3	[illegible]	[2]	43.6	[illegible]	39.0	42.1	3.1
May	51.4	2.2	24.2	1.4	[illegible]	0.2	84.4	11.2	73.2	[illegible]	13.3
June	34.7	.8	13.6	.5	2.9	.5	53.0	3.7	49.3	57.3	8.0
July	[illegible]	.5	6.8	2.0	2.6	[illegible]	24.5	.3	24.2	22.8	−1.4
August	17.7	[illegible]	7.0	.7	3.2	[illegible]	30.2	4.8	25.4	25.3	−0.1
September	11.1	[illegible]	[illegible]	.5	[illegible]		[illegible]	4.3	14.3	15.3	1.0
October	3.8	.4	[illegible]	.6	[illegible]	.6	8.9	6.9	2.0	6.2	4.2
November	1.3	.4	1.8	[illegible]	[illegible]	.6	15.4	[illegible]	−.1	1.8	[illegible]
December		[1].2	[illegible]	[illegible]	[illegible]	[illegible]	11.4	[illegible]	[illegible]		0.5
Total	[illegible]	7.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[1] Estimated. [2] No record.

[illegible]

An analysis of the 1936 return flow to the section of the Rio Grande between the Alamosa and Lobatos gages is given in table 41. Exclusive of the inflow of Trinchera, Conejos and Culebra creeks, totaling 168,400 acre-feet, this shows a net return in the section of 53,000 acre-feet, 38,800 acre-feet from Alamosa to Trinchera Creek and 14,200 acre-feet from Trinchera Creek to the Lobatos gage. Including the inflow of the three creeks, the total return in the section was 221,400 acre-feet. For the years 1930 to 1935 data are available to derive the total return in this section, but the lack of a record in these years of Rio Grande flow above Trinchera Creek prevents segregation of the return to the two sections, above and below Trinchera Creek. An es-

Table 41.—*Return water between Alamosa and Lobatos gages, San Luis Valley, 1936*

[Unit 1,000 acre-feet]

Month	Rio Grande at Alamosa	Rio Grande above Trinchera Creek	Difference (1)−(2)	Diversions below Alamosa	Return flow Alamosa to Trinchera Creek (4)−(3)	Rio Grande near Lobatos	Total inflow Trinchera Creek to Lobatos (6)−(2)	Trinchera Creek at mouth	Conejos River and Culebra Creek at mouths [1]	Net return flow Trinchera Creek to Lobatos (7)−(8+9)	Net return flow Alamosa to Lobatos (5)+(10)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
January	9.4	[2] 9.4	0		0	15.4	6.0	[illegible]	4.0	1.3	[illegible]
February	11.7	[2] 12.7	−1.0		1.0	19.8	7.1	[illegible]	4.6	1.5	[illegible]
March	4.9	[2] 10.1	−5.2		5.2	16.0	5.9	[1] .7	3.8	1.4	[illegible]
April	2.8	[2] 4.6	−1.8		1.8	60.4	55.8	[1] .3	[illegible]	1.2	3.0
May	5.0	11.2	−6.2	1.5	7.7	78.7	67.5	.2	65.2	2.1	[illegible]
June	2.9	3.7	−.8	3.4	4.2	11.0	7.3	0	4.9	[illegible]	[illegible]
July	2.6	.3	2.3	3.0	.7	1.1	.8	0	.2	.6	[illegible]
August	3.2	4.8	−1.6	1.2	2.8	9.0	4.2	[illegible]	2.9	.9	[illegible]
September	1.5	4.3	−2.8		2.8	7.7	3.4	[illegible]	2.4	.4	3.2
October	1.6	6.9	−5.3		5.3	13.9	7.0	1.2	5.4	.4	5.7
November	10.9	15.5	−4.6		4.6	24.7	9.2	2.0	7.1	[illegible]	[illegible]
December	12.2	14.9	−2.7		2.7	23.3	8.4	[1] 1.1	[illegible]	[illegible]	[illegible]
Total	68.7	98.4	−29.7	9.1	38.8	281.0	182.6	8.2	160.2	[illegible]	[illegible]

[1] From May to November the flow of Culebra Creek was only 106 acre-feet, 10 in July and 96 in August.

[2] Estimated.

timate of the net return requires also that Trinchera Creek inflow be estimated. The data are given in table 42. This table indicates a mean return flow, exclusive of the creek inflow, Alamosa to Lobatos, for the 7-year period 1930–36, amounting to 57,200 acre-feet, with a range from 29,100 acre-feet in 1931 to 100,800 acre-feet in 1932.

For the remainder of San Luis Valley, comprising the closed basin and southeast area, few return-flow data are available. In the closed basin there is no return to Rio Grande except by the Rio Grande drain. Otherwise, return from irrigation travels toward the sump and is lost by evaporation or through transpiration by native vegetation. In the southeast area the irrigable lands far exceed the area which can be served by the water supply of the streams, which are completely regulated. With reuse of return flow in the lower areas, there is, therefore, little return to Rio Grande.

Table 42.—*Return water between Alamosa and Lobatos gages, San Luis Valley, 1930–36*

[Unit 1,000 acre-feet]

Year	Rio Grande at Alamosa	Rio Grande near Lobatos	Difference (1)−(2)	Diversions below Alamosa	Total inflow Alamosa to Lobatos (4)−(3)	Trinchera Creek at mouth	Conejos River at mouth	Net return flow Alamosa to Lobatos (5)−(6+7)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1930	90.9	270.4	−179.5	4.9	184.4	6.0	119.5	58.9
1931	65.6	125.5	−59.9	7.4	67.3	[1] 4.0	34.2	29.1
1932	190.1	596.4	−406.3	12.5	418.8	10.0	308.0	100.8
1933	66.7	237.0	−170.3	7.5	177.8	6.0	110.9	60.9
1934	48.9	98.8	−49.9	9.1	59.0	4.0	20.8	34.2
1935	98.8	360.1	−261.3	13.5	274.8	[illegible]	203.0	63.3
1936	68.7	281.0	−212.3	9.1	221.4	8.2	160.1	53.1
Mean	89.9	281.3	−191.4	9.1	200.5	6.7	[illegible]	57.2

[1] Estimated.

Note.—Culebra Creek Inflow probably negligible; taken as zero.

The Middle Section

From the results of the 1936 investigation some data are available to furnish an idea of return flow in the Middle Rio Grande Conservancy District. As brought out in the ground-water investigation of this area, the flow in riverside drains of the district is made up almost entirely of direct seepage from the river. The flow in the interior drains may therefore be taken as representing the total return flow from irrigation plus intercepted underflow from the mesas. No determination of the latter has been made but in the report of the ground-water investigation it is estimated at 50,000 to 100,000 acre-feet for the valley from Pena Blanca to San Marcial, a distance of 150 miles.

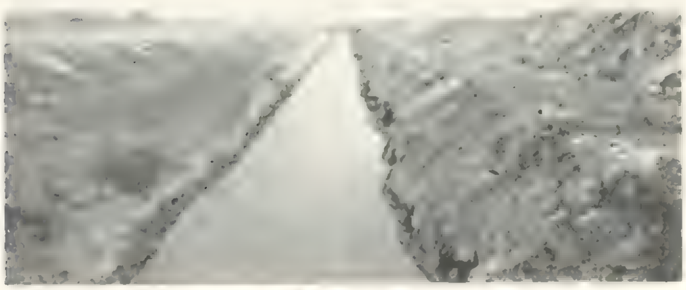
The flow of the interior drains of the conservancy district as measured in 1936 is given by divisions in table 43. The 1936 irrigated acreage for each division

Table 43.—*Discharge of interior drains of Middle Rio Grande Conservancy District, 1936*

[Unit acre-feet]

Month	Division				District total	Combined flow of Albuquerque and Belen divisions in percent of annual flow
	Cochiti	Albuquerque	Belen	Socorro		
January	400	3,500	4,900	2,700	11,500	6.3
February	440	2,700	4,100	2,500	9,740	5.1
March	400	3,400	4,300	[illegible]	11,100	5.8
April	330	5,500	6,100	3,400	15,330	8.7
May	470	6,600	7,500	4,300	18,870	10.6
June	[illegible]	7,800	6,700	3,100	18,000	10.9
July	430	8,200	6,200	2,700	17,530	10.8
August	340	7,400	6,200	2,300	16,240	10.2
September	420	6,800	6,200	2,400	15,820	9.8
October	[illegible]	5,600	5,100	2,800	13,910	8.0
November	[illegible]	4,400	5,300	2,600	12,720	7.3
December	[illegible]	3,500	5,100	2,700	11,730	6.5
Year	[illegible]	65,400	67,700	34,500	172,490	100.0
Acreage irrigated	[illegible]	22,819	23,895	7,237	59,159	
Drain flow acre-feet per irrigated acre	0.94	[illegible]	2.84	4.77	2.92	
Percent of [illegible]	[illegible]	[illegible]	28.1	52.8	[illegible]	

[illegible]



[illegible]

[illegible]

is given also and the drain flow in acre-feet per irrigated acre. The latter figures for all divisions except Cochiti appear to be rather high, especially that of 4.77 acre-feet per acre for the Socorro division. This division is very narrow, and probably its interior drains receive some direct seepage from the river. Some waste may also be included in the drains at the points of measurement.

The monthly distribution of the drainage return as derived from the combined flow in the Albuquerque and Belen divisions is shown in the last column of table 43.

The data obtained in 1936 do not afford a comparison of the drainage return with net diversions. Gross diversions only are available, and because in the conservancy district a great amount of water is wasted back to the river below the points of diversion measurements (only a small portion of this waste was measured), there is a wide difference between gross and net diversions. The gross diversions to the divisions of the conservancy district as given by the 1936 measurements are shown in table 44. These figures represent the diversions to the division less the discharge of the canals flowing past the lower boundary of the division into the succeeding division. The total of the gross diversion for the district is 617,000 acre-feet, and the total drain flow of 172,490 acre-feet is 28 percent of the total gross diversion. The drain flow in percent of the gross diversions by divisions is given in the last line of table 43.

The Elephant Butte-Fort Quitman Section

Except for the Rio Grande Project, drainage data for this section are incomplete. On the project the discharges of the drains of each division, Rincon, Mesilla, and El Paso, have been measured for many years, and the data are available to derive the net diversions in each division. Comparison of drainage return and net diversions is therefore possible. Table 45 gives the net diversions and drainage return in acre-feet and in percent of diversions for each division and for the total project for the years 1930 to 1936, inclusive. It will be noted that the percentage return is high, the 7-year mean for the project being 50.3 percent. An important factor contributing to high return is seepage losses from the very large mileage of main canals and laterals required to irrigate the long narrow valleys.

TABLE 44.—*Gross river diversions in the Middle Rio Grande Conservancy District, 1936*

[Unit acre-feet]

Month	Division: Cochiti	Division: Albuquerque	Division: Belen	Division: Socorro	District total
January	0	[1]0	0	[1]0	0
February	0	[1]0	0	[1]0	0
March	0	[1]0	0	[1]0	0
April	6,500	29,700	36,100	6,600	78,900
May	10,000	37,800	39,800	11,200	98,800
June	9,000	36,300	37,800	11,400	94,500
July	9,800	34,400	30,600	7,600	82,400
August	9,800	30,000	32,300	11,000	83,100
September	7,300	27,400	26,700	7,800	69,200
October	7,900	24,200	17,800	6,400	56,300
November	7,800	10,700	19,600	3,300	41,400
December	6,900	5,500	0	0	12,400
Year	75,000	236,000	240,700	65,300	617,000
Acreage irrigated	5,208	22,819	23,895	7,237	59,159
Diversions in acre-feet per irrigated acre	14.40	10.35	10.08	9.03	10.42

[1] Estimated.

The monthly distribution of the drainage return as derived from the 1930–36 means for the total project drainage is as shown in table 46.

Ground Water

Another source of water supply in the upper basin is the water collected and stored in its underground reservoirs. These are charged by percolation from rainfall and from water applied in irrigation, and by seepage from canals and natural stream channels. Withdrawals or discharge from the ground-water basins may occur through pumping, the flow of artesian wells and springs, evapo-transpiration losses at the ground surface where the water table is high, artificial drainage, and underflow, of which the latter may appear as inflow to stream channels at lower elevations.

TABLE 46.—*Monthly distribution of drainage return, Rio Grande Project, 1930–36*

Month	Total project drainage return mean for years 1930–36, inclusive: In 1,000 acre-feet	In percent of annual	Month	Total project drainage return mean for years 1930–36, inclusive: In 1,000 acre-feet	In percent of annual
January	18.4	5.2	August	41.0	11.5
February	18.0	5.1	September	37.1	10.4
March	24.7	7.0	October	29.4	8.3
April	32.1	9.0	November	23.1	6.5
May	35.0	9.8	December	21.1	5.9
June	36.2	10.2			
July	39.5	11.1	Annual	355.6	100.0

The principal ground-water basins for consideration with respect to water supply in the upper basin are these underlying the San Luis Valley, the Middle Valley from Cochiti to San Marcial, and the Rincon, Mesilla and El Paso Valleys. In none of these areas has ground water been utilized to any appreciable extent as a primary or basic source of supply for irrigation, although the extensive control of ground water for the practice of subirrigation in western San Luis Valley areas might be considered as an exception to this statement. Moreover, there appears to be no immediate

TABLE 45.—*Net diversions and drainage return, Rio Grande Project, 1930–36*

[Unit 1,000 acre-feet except as otherwise noted]

Year	Rincon: Net diversion	Rincon: Drainage return: Amount	Rincon: Drainage return: Percent of diversions	Mesilla: Net diversion	Mesilla: Drainage return: Amount	Mesilla: Drainage return: Percent of diversions	El Paso: Net diversion	El Paso: Drainage return: Amount	El Paso: Drainage return: Percent of diversions	Project total: Net diversion	Project total: Drainage return: Amount	Project total: Drainage return: Percent of diversions
1930	64.4	31.9	49.5	424.1	183.8	43.4	268.1	132.5	49.4	[illegible]	348.2	46.0
1931	64.0	36.7	57.3	410.7	196.5	47.9	237.0	131.2	55.4	711.7	364.4	51.2
1932	73.9	39.2	53.0	439.5	194.1	44.2	244.6	138.0	56.4	758.0	371.6	49.0
1933	69.4	41.0	59.1	416.3	205.4	49.4	243.4	137.2	56.4	729.1	383.6	52.6
1934	82.7	40.9	49.5	426.3	217.8	51.1	265.3	132.8	50.1	774.3	391.5	50.5
1935	51.3	26.8	52.3	298.7	167.1	56.0	198.8	109.5	55.1	548.8	303.4	55.3
1936	63.0	28.5	45.3	368.8	185.2	50.2	237.4	112.9	47.6	669.2	326.6	48.8
Mean	67.0	35.0	52.2	397.8	192.9	48.5	242.1	127.7	52.7	706.9	355.6	50.3

probability of extensive ground-water development as a basic supply, except as the recurrence of dry years may result in increased pumping in San Luis Valley, or Wagon Wheel Gap Reservoir, if constructed and accompanied by power development, may create a condition favorable to ground-water pumping in that valley. This investigation accordingly has been concerned with the relation of ground water to present utilization of surface supplies and to present losses by evaporation and transpiration in seeped areas, rather than with potentialities of ground water as a basic supply. It is to be observed, in general, that extensive development of ground water for irrigation would add no new water to the Upper Rio Grande Basin and that recharge of the ground-water basins would necessarily involve a draft on surface supplies which are now utilized otherwise. The chief element to be considered in such a development would be the redistribution of the availability and use of present supplies and the resulting effect upon the water supply of lower major units.

As a part of the Rio Grande joint investigation, the nature and occurrence of ground water in the San Luis and Middle Valleys was studied by the Ground Water Division of the Geological Survey and the report of that study constitutes part II of the present report. Some of the salient features of the study are reviewed in the following paragraphs.

San Luis Valley

The entire floor of San Luis Valley is underlain by a body of unconfined water at shallow depth. The only major development of this body of ground water, with the exception of its control for subirrigation in parts of the valley, has been the construction of stand-by irrigation wells in the agricultural area on the west side of the valley, where the wells are used in periods of water shortage. Beneath the shallow ground waters, and separated from them by a confining bed, lies a large body of artesian water, occupying numerous strata in the valley fill. The artesian water has been developed extensively for domestic, stock, and irrigation purposes, more than 6,000 flowing wells having been drilled. The principal features of the 1936 investigation were the measurements of water levels and fluctuations of the shallow ground water and an inventory of the discharge of artesian wells.

Unconfined or shallow ground water. The shallow valley fill which contains the unconfined ground water is present under the valley floor as a continuous deposit ranging in thickness from 10 to 90 feet. Beneath it are the impermeable beds which form the upper confining surface of the artesian basin. At the edges of the valley floor these impermeable beds "feather out" and there are marginal strips of unconfined ground water. This water, moving laterally toward the center of the valley, is a common source of supply for both the shallow and artesian basins.

The yield of shallow wells in the valley ranges widely in accordance with the character of the sediments of the valley fill. An investigation of wells sunk for irrigation pumping in nearly every part of the valley showed, in general, that the successful wells are all on the west side of the valley, on or near the alluvial fans. The greatest concentration of irrigation wells is on the Rio Grande alluvial fan. Another group is east of the Monte Vista Canal in the Bowen-Carmel area and there are a few scattered wells on either side of Rio Grande in the vicinity of Parma. The average yield of wells in these areas is about 850 gallons per minute; some wells report yields up to 1,600 gallons per minute. In the central and eastern parts of the closed basin, practically all attempts to pump for irrigation have failed, chiefly because of the inability of the sediments to yield water readily.

The form of the water table in the closed basin as shown by ground-water contours plotted for October 1936 shows a close resemblance to the general form of the land surface. The water table slopes from the west, north, and east toward the trough of the valley, and the lowest point is about 6 miles south of San Luis Lake. Here the contours indicate a closed depression with the water table sloping toward it on all sides. From the Rio Grande alluvial fan the movement is toward the northeast, east, and southeast, but there is indication that along the south side of this fan, and north of the river between Monte Vista and Alamosa, the movement is toward the Rio Grande. With the latter exception, the October 1936 contours indicate that none of the ground water of the closed basin is moving out of the area.

Except on steep alluvial slopes and fans, where it may be 100 feet or more, the depth to ground water over most of the valley floor does not exceed 10 feet. Depths-to-water contours for July 1936 show less than 5 feet over approximately 70 percent of the closed basin and from 5 to 8 feet over 20 percent of it. In the Bowen-Carmel district and the general area east to the river, they show less than 5 feet in most places, with an increase to the west where the alluvial fan of Gato and Alamosa Creeks begins.

Fluctuations of the water table maintain a balance between the annual amount of water replenishing the underground supply and the annual amount withdrawn or discharged. In San Luis Valley the fluctuations follow closely the seasons of the year, but they are not uniform throughout the valley. In the western areas, where subirrigation is practiced, there is a sharp and pronounced rise of the water table at the beginning of the irrigation season, usually about April 1. At

the end of the irrigation season there is a gradual decline which continues until the beginning of the next season. In the northern, central, and eastern parts of the closed basin, cropped lands give way to meadow and brush lands. Water is applied to most of the meadowlands but not to lands supporting other native vegetation. However, such vegetation is comprised of plants that "feed" on ground water, resulting in a lowering of the water level during the growing season. A gradual rise ensues through the winter, after which percolation from spring thaws brings about a sharp rise. The water level then remains high until the "transpiration draft" is resumed. Lowering of the water table due to standby irrigation pumping in 1936 was quite marked on the Rio Grande alluvial fan and in the Bowen-Carmel area. The decline began in June and there was no appreciable recovery until well into September.

The sources of ground-water recharge in San Luis Valley are stream flow, irrigation diversions, artesian well flow, and precipitation on the valley floor. All streams entering the valley must flow across the bordering alluvial slopes, the texture of which is conducive to high percolation, and large losses to ground water result. Measurements of Rio Grande losses in a short section below the Del Norte gage, situated close to the apex of the Rio Grande alluvial fan, range as high as 100 second-feet or more. The highest measured loss between Del Norte and Monte Vista in 1936 was 2,345 acre-feet during March and April, equivalent to a continuous flow of 19 second-feet. Similarly, on Conejos River between the Mogote gage and Conejos, losses have been measured in certain periods of the year that ranged up to 22 second-feet.

During the irrigation season practically the entire flow of Rio Grande and other streams entering the valley from the west is diverted for irrigation, largely on the Rio Grande alluvial fan and that of Gato and Alamosa Creeks. With the types of soil and the methods of subirrigation prevailing, there is abundant opportunity for ground-water recharge from irrigation in these areas. Without doubt there is now a much larger recharge to the ground water than occurred in days before irrigation was practiced. This is evidenced by the extensive system of drains built to lower the water level and to carry away excess ground water.

Very little of the artesian well flow passes out of the valley as stream flow, and much of it goes to recharge ground water. A substantial part of this recharge is by leakage from wells inadequately cased.

A rough measure of ground-water recharge from rainfall penetration in the central portion of the closed basin was afforded by data on the rise in the water table and the specific yield of water bearing materials at seven wells situated outside of the influence of any recharge from irrigation. In the period from July 20 to October 15, 1936, the recorded precipitation at Garnett was 5.78 inches. In the same period the average rise of the water table in the wells was 0.94 foot. On the basis of the average specific yield of 30.5 percent, the recharge to ground water amounted to 3.7 inches, or 64 percent of the rainfall as recorded at Garnett. Since the texture of the soil and the amount and intensity of rainfall range widely throughout the valley, it follows that ground-water recharge from rainfall penetration must also range widely.

Discharge of ground water in the shallow valley fill of San Luis Valley is by evaporation and transpiration, underflow, artificial drainage, and pumping. Conditions in the valley, especially in the central and eastern portions of the closed basin, are favorable for the disposal of large quantities of ground water by evaporation and transpiration.

As previously stated, discharge by underflow to Rio Grande occurs in the section between Del Norte and Alamosa. The data of tables 35 and 36 in the preceding section dealing with return water furnish some conception of its amount. The return flow indicated by these tables includes some creek and surface drain inflow. Eliminating this in the 1936 table, using available records and best estimates of its amount, gives seepage gains for the year of 17,200 acre-feet between Del Norte and Monte Vista and of 35,500 acre-feet between Monte Vista and Alamosa. The largest monthly gain in the section in 1936 was 10,040 acre-feet in August, equivalent to a continuous flow of 163 second-feet.

Of the ground-water discharge through the net work of drains on the valley floor, much is rediverted for irrigation and the remainder is ultimately discharged either to Rio Grande or to the sump in the closed basin.

The quantity of ground water withdrawn by pumping varies notably from year to year. Practically all of the pumps have been installed as standby irrigation plants, and this development has occurred largely within the last five years. When there is a shortage in stream flow, as in 1936, pumping is at a maximum. A reconnaissance in 1936 showed that there were 176 irrigation pumping plants in the valley. Many of them were just being installed. From reported discharges by owners or operators, the total output of all plants pumping continuously was estimated at 660 acre-feet per day.

Confined or artesian water.—Flowing wells can be obtained in the San Luis Valley over an area embracing 1,430 square miles or, measured at its extremities, an area 66 miles north and south and 32 miles east and west. All the essentials of an ideal artesian system are present in the valley.

Corresponding principally to the distribution and character of the sediments in the aquifers, the valley may be divided into fairly well defined sections of high flow and low flow on the basis of the average yields of the wells. Three localities in particular have appreciably higher flows than the average. These are (1) the district southwest of Alamosa in the vicinity of Henry station and westward to the Fountain neighborhood; (2) an area several sections in extent, the center of which is about 6 miles northeast of Alamosa; and (3) an area extending southward from the vicinity of Russell Lakes to Veteran School. The largest and strongest flows of the valley occur in the last named area.

Contrary to the usual history of artesian basins, the area of flow in San Luis Valley has increased over a period of development covering the last 30 years. This is shown by comparison of the area of flow in 1906, as delineated by Seibenthal, with the area determined by the field work of 1936. The increase is readily apparent on the gentler alluvial slopes, such as the Rio Grande fan, but not where slopes rise steeply from the valley floor. Thus the boundary of the flow area has moved westward more than a mile in some places along the Rio Grande alluvial fan and southward about 2 miles near Manassa. The explanation lies in the shift of irrigation development toward the west, and the resulting increase in recharge to the artesian basin from irrigation diversions.

As in the case of the shallow ground-water basin, recharge to the artesian basin is from stream flow, irrigation diversions, and precipitation. For the artesian basin, however, the area of recharge is confined to the marginal strip of the valley overlying the upturned edges of the artesian aquifers.

Water is naturally discharged from the artesian basin by springs and artificially by wells. There are several springs in the valley along the boundary of the area of flow. The discharge of McIntire Springs, one of the larger, remains practically constant at close to 19 second-feet throughout the year. On the other hand, the discharge of Diamond Springs, about 4 miles southwest of La Jara, has increased progressively during the last 30 years from probably less than 1 second-foot to more than 24 second-feet, thereby furnishing strong additional evidence of the increase in recharge of the artesian basin due to irrigation development. Other springs on the west side of the valley are those comprising the source of Spring Creek and Russell Springs. Table 47 lists the artesian springs and gives their average discharge as measured in 1936. The indicated total average discharge of 65.7 second-feet represents an annual discharge of 47,600 acre-feet.

An estimate of the total artesian water discharged annually by wells in the valley is afforded by the inventory of wells which was made in 1936. On the basis of this inventory, it is estimated that there are 6,074 artesian wells in the valley, with an average annual discharge of about 119,000 acre-feet. Of this number, 1,380 wells in the towns of Alamosa, Center, La Jara, Monte Vista, and Sanford discharge annually about 8,700 acre-feet. The discharges of the wells range from a trickle to 350 gallons per minute, with an average of about 12 gallons per minute. If all wells in the valley were allowed to flow unrestricted, the annual discharge would be about 142,000 acre-feet.

TABLE 47.—*Discharge of artesian springs in San Luis Valley, 1936*

[illegible]	[illegible]	[illegible] second-feet
[illegible]	1, Nov. 23	[illegible]
Spring Creek	1, Nov. 27	[illegible]
[illegible]		(1)
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]		65.7

[illegible]

Middle Valley

The ground-water investigation in the Middle Valley covered the valley area from about 15 miles south of White Rock Canyon to about 7 miles north of San Marcial. The principal feature was the measurement of water levels and fluctuations in approximately 1,000 observation wells. Certain studies were made and a small amount of experimental work was carried on in an endeavor to clarify some of the basic problems connected with the source, motion, and disposal of the ground water, but the time and work involved in the location and periodic measurement of the large number of wells left little opportunity in the one season for the special and experimental type of investigation needed for such clarification.

Movement of ground water.—Observations on the movement of ground water are based on the maps of part II, plates 6 to 9, inclusive, which give the water-table altitudes by contours and the depths below ground surface by areal divisions, as derived from the data of well readings during October 1936. Lacking the requisite data for derivation of annual means, the October readings were used because all available evidence indicated that the water table during that month was at approximately its mean position for the year. The most obvious characteristic of the ground-water flow is its predominant downstream movement. From the vicinity of Algodones, where the water table has an altitude of 5,080 feet, to a point 17 miles south of Socorro, the water table falls 585 feet, an average of 5 feet per mile. This corresponds, of course, to the fall of the river in the same distance. The lateral slopes

of the water table, and consequently the lateral movements of the ground water vary considerably in different parts of the valley, depending principally on the spacing of the drains. In general, the lateral slope of the water table varies more or less inversely with the width of the valley. It is most pronounced in the Socorro division, where it is as high as 22 feet to the mile, and least pronounced in the Belen division. Throughout most of the length of the river, the water table slopes from the riverside drains to the interior drains.

Due to the great variation throughout the valley in the transverse direction of water movement according to the spacing and distribution of drains and canals, no short generalized areal description of the movement of ground water is possible. In a section at the upper end of the Albuquerque division, the water table slopes from the edge of the mesa to the river, and indicates an accretion to the river from the arroyos and mesa slopes and to some extent by leakage from the Bernalillo and Algodones acequias. However, from this section to the lower end of the Middle Rio Grande Conservancy District at the north line of the Bosque del Apache Grant there is every variation in direction of ground-water movement: to interior drains from mesa sides and riversides; from the river to riverside drains or beyond them to interior drains; from the mesa or border canals to interior drains, or to riverside drains where there are no intermediate interior drains; and from canals to drains; etc. In the Bosque del Apache Grant, which is an undrained area, the water table slopes rather uniformly southward; it shows comparatively little distortion, and lateral flow is small.

Water-table fluctuations.—The determination of normal seasonal fluctuations of the water table was not possible in the few months of the present investigation. It was found, however, that the seasonal fluctuations in irrigated and unirrigated areas are opposite in trend. As in the case of portions of San Luis Valley, the irrigated areas receive water in the growing season in excess of their demand and consequently the water table rises in summer. It then falls to a lower position in winter. In the unirrigated areas the vegetation demands more water in summer than can be supplied by ground-water flow, and hence in these areas the water table falls in summer. It rises in winter, when there is no draft by native vegetation. These typical changes are shown by the average fluctuation in the various districts of the valley between July and October 1936 given in table 49. The Bosque del Apache area, unirrigated except by overflow from the Socorro main canal at the northern border, showed a rise in the water table, July to October of 0.86 foot. In none of the Middle Valley districts listed is all of the land irrigated. Hence the declines of the water table given in table 49 are not entirely representative of the change in irrigated areas. However, the more heavily irrigated areas show the greater declines, ranging up to 1.62 feet for the Barr district.

Source of ground water.—Ground water in the Middle Valley has several sources. Part of it comes by underflow from the mesas on either side of the valley, part from seepage from the river, part from seepage from canals, and part from seepage from irrigated lands. To determine the source or sources of the ground water in any particular locality is difficult. A substantial amount must come as underflow from the higher lands bordering the floodplain of the river. This probably occurs as a general seepage throughout the length of the valley and as concentrations near the arroyos which intermittently receive larger quantities of water. The water-table map shows steep gradients from the debouchures of the large arroyos, notably Tijeras, in the upper part of the Barr district, and Hell Canyon, above Peralta. The volume of this increment to the ground water of the floodplain has not been determined. An approach to the problem is discussed in a subsequent paragraph after consideration of ground-water conditions prior to drainage. It is concluded there that available data indicate an average annual flow from the hillsides to the valley of about 0.25 second-foot per lineal mile of border, or a total on both sides of the valley throughout its length of about 50,000 acre-feet. It is concluded further that the maximum flow that should be assumed, based on minimum accretions to the interior drains, probably does not exceed 100,000 acre-feet per year.

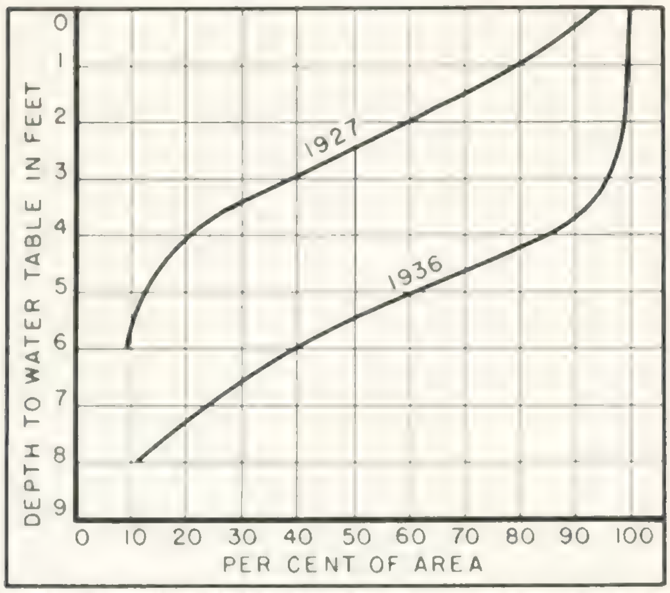
Rio Grande is, without doubt, itself the source of most of the water in the riverside drains. In the cultivated area beyond the riverside drains, some of the ground water also comes from the river. In general, the latter condition is likely to occur where intermediate drains lie within a mile of the riverside drains, a situation most prevalent in the Socorro division. As shown by the quality of water investigation, the water in the interior drains of the Socorro division has, on the whole, a lower mineral content than that in the interior drains of the remainder of the Middle Valley.

Some water-table divides in the interior of the valley follow approximately irrigation canals, indicating that the latter are another source of ground water. Data are largely lacking to define either the degree or the amount of their contributions.

It is doubtful whether any significant part of the ground water has its origin in the scant precipitation on the valley floor. This doubt applies particularly to the summer period. Precipitation does, however, have a noticeable effect in reducing ground-water consumption, and this effect is manifested in fluctuations of the water table.

There seems little doubt that in most areas of the Middle Valley seepage from irrigated lands is the main source of ground water. This is indicated by the pronounced drop in ground-water levels in irrigated districts as measured in 1936 between July, when irrigation was intense, and October, when irrigation had decreased but the canals were all operating.

From present information it would seem that gains and losses between riverside drains and the lands are of the same order of magnitude so that the discharge of the riverside drains, excluding surface waste into them, represents approximately the quantity of water withdrawn by seepage from the river, while the discharge of the interior drains represents water derived from immediate sources other than the river that are saved from evaporation and transpiration.



[illegible]

Depth to ground water.—Based on data of the October 1936 well readings, the depths to ground water throughout the Middle Valley are summarized in table 48 which gives the acreage in each subdivision of the valley with ground water at various depths. In order to derive a comparison between 1936 ground-water conditions and those which obtained before drainage construction, and particularly to establish the average lowering of the water table due to the latter, the 1936 depths to ground water were compared to the average of those for 1926–27 as given in the 1928 Burkholder report of the Middle Rio Grande Conservancy District. The comparison is shown in table 49. This table also gives the average rise or fall of the water table in the various valley subdivisions from July to October 1936.

The average lowering of the water table under the entire valley from 1927 to 1936 was 3 feet. Depths to water of less than 3 feet are shown for October 1936 in 4 percent of the total valley area; between 3 and 4 feet in 11 percent of the area; between 4 and 6 feet in 46 percent; between 6 and 8 feet in 28 percent; and more than 8 feet in 11 percent. The data for the valley as a whole are shown graphically in figure 22. The best drained districts are indicated to be the Coralles, the Peralta-Tome, and the San Acacia-Lemitar-Socorro.

Conditions before drainage.—A cooperative ground-water investigation in the Middle Valley conducted in the period 1917–22 also furnishes some data for

Table 48.—[illegible]

District		Depth to water, in feet								Total acreage		
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	777.00	[illegible]	[illegible]	7,043.00
	[illegible]	0	.29	.17	4.21	[illegible]	[illegible]	[illegible]	11.10	[illegible]	0	
[illegible]	[illegible]	[illegible]	[illegible]	0	0	352.00	1,722.00	[illegible]	355.00	[illegible]	631.00	3,748.00
	[illegible]	0	[illegible]	[illegible]	0	11.28	55.24	[illegible]	[illegible]	[illegible]	20.25	
[illegible]	[illegible]	[illegible]	[illegible]	31.00	[illegible]	2,072.00	[illegible]	[illegible]	[illegible]	[illegible]	1,468.00	[illegible]
	percent	[illegible]	[illegible]	[illegible]	[illegible]	14.80	46.70	[illegible]	[illegible]	[illegible]	10.48	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11.00	[illegible]	7,025.00	[illegible]	[illegible]	12,246.00	1,887.00	14,133.00
	[illegible]	[illegible]	0	[illegible]	.10	[illegible]	57.36	[illegible]	[illegible]	[illegible]	15.41	
[illegible]	[illegible]	0	[illegible]	178.00	[illegible]	[illegible]	[illegible]	[illegible]	490.00	[illegible]	0	4,543.00
	percent		.28	3.90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.00	0	
[illegible]	[illegible]	0	0	[illegible]	[illegible]	[illegible]	[illegible]	1,760.00	1,490.00	20,056.00	0	[illegible]
	percent		[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	7.43	100.00	0	
[illegible]	[illegible]		0	64.00	[illegible]	[illegible]	[illegible]	[illegible]	3,120.00	23,820.00	674.00	24,494.00
	[illegible]	0		[illegible]	.99	8.24	47.10	[illegible]	[illegible]	100.00	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	376.00	583.00	3,815.00	[illegible]	[illegible]	[illegible]	0	8,499.00
	[illegible]	.81	[illegible]	4.98	4.43	[illegible]	44.88	[illegible]	2.62	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	133.00	235.00	408.00	1,843.00	1,437.00	580.00	554.00	[illegible]	0	5,344.00
	percent	[illegible]	[illegible]	4.40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.00	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	186.00	322.00	1,107.00	3,395.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	1.71	1.75	3.02	10.40	31.85	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	0	[illegible]	91.00	415.00	2,520.00	[illegible]	[illegible]	[illegible]	0	6,036.00
	percent	[illegible]	0	0	1.51	[illegible]	41.75	[illegible]	[illegible]	[illegible]	0	
[illegible]	[illegible]	[illegible]	811.00	[illegible]	2,040.00	1,476.00	544.00	[illegible]	[illegible]	[illegible]	448.00	[illegible]
	percent	[illegible]	[illegible]	23.80	27.42	19.83	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
Valley total [2]	[illegible]	223.00	[illegible]	[illegible]	2,852.00	13,041.00	52,554.00	31,981.00	[illegible]	[illegible]	1,660.00	119,983.00
	percent	[illegible]	.62	[illegible]	2.46	11.30	45.64	[illegible]	[illegible]	[illegible]	1.04	

[1] [illegible]
[2] [illegible]

TABLE 19.—*Comparison of depths to ground water in the Middle Valley in 1927 and 1936*

District	Year	Percentage of area with depth to ground water over—								Unsurveyed area in percent of surveyed	Average depth to water, in feet	Average rise of water table, in feet	Average [illegible] in 1936 from July to October, in feet	Area, in acres		
		8 feet	6 feet	4 feet	3 feet	2 feet	1 foot	0 foot	Above ground surface					Surveyed	Unsurveyed	Total
Algodones-Bernalillo	1927		20.97	39.71	....	70.21	86.49	95.23	4.77	1.72	3.58			11,[illegible]	197	12,180
	1936	11.10	38.33	[illegible]	95.33	[illegible]	99.71	100.00			5.72	2.14	−0.33	7,043	0	7,043
Corrales	1927	....	2.86	[illegible]	....	51.71	69.52	91.64	8.36	0	2.48			3,038	[illegible]	[illegible]
	1936	11.[illegible]	[illegible]	88.72	100.00					20.25	5.73	3.25	−.30	3,117	[illegible]	[illegible]
Alameda-Albuquerque	1927	....	8.02	13.18	....	37.19	[illegible]	88.48	11.52	0	1.99			14,675	0	[illegible]
	1936	13.28	34.01	80.71	95.51	99.78	100.00			10.48	5.61	2.62	−.68	13,989	1,468	15,457
Atrisco-Pajarito-Isleta	1927	....	7.22	[illegible]		72.60	89.25	96.87	3.13	1.17	3.09			15,823	186	16,009
	1936	4.31	27.58	[illegible]	[illegible]	100.00				[illegible]	5.41	2.32	−.86	12,246	1,887	14,133
Barr	1927		0	7.60	....	[illegible]	72.59	91.18	8.82	[illegible]	1.91			4,185	0	[illegible]
	1936	[illegible]	19.62	57.72	86.82	[illegible]	99.72	100.00		[illegible]	1.80	2.89	−1.62	4,543	0	4,543
Peralta-Tome	1927	....	9.33	[illegible]		47.99	69.52	93.24	6.76	0	2.32			20,541	0	[illegible]
	1936	7.43	46.13	94.88	[illegible]	100.00				0	5.99	3.67	−.19	[illegible]	0	20,050
Los Lunas-Belen	1927	....	10.54	22.39	....	75.39	94.24	99.88	.12	.37	3.23			[illegible]	92	[illegible]
	1936	13.10	43.40	[illegible]	98.74	99.73	100.00			2.82	5.97	2.74	−.40	23,820	674	24,494
San Juan	1927	....	1.51	21.69		[illegible]	91.34	96.97	3.03	.39	2.87			6,198	[illegible]	6,224
	1936	2.62	33.77	[illegible]	[illegible]	89.94	94.92	[illegible]	.81	0	5.10	2.23	.05	8,499	0	8,499
San Francisco	1927	---	11.52	25.65	....	39.26	51.91	75.48	24.52	0	2.12			4,616	0	4,616
	1936	[illegible]	21.24	48.11	82.59	90.23	94.63	97.12	2.88	0	4.50	2.38	1.39	[illegible]	0	5,344
San Acacia-Lemitar-Socorro	1927		12.47	24.36	....	53.55	72.79	88.78	11.22	4.76	2.66			13,437	640	14,077
	1936	[illegible]	51.27	83.12	93.52	96.54	98.29	100.00		0	6.13	3.47	.22	10,636	0	10,636
San Antonio	1927	---	4.81	21.63		63.31	87.10	97.65	2.35	37.34	2.83			5,016	2,620	7,636
	1936	15.30	49.86	91.61	[illegible]	100.00		...		0	6.16	3.33	−.07	6,036	0	6,036
Bosque del Apache Grant	1927		0	11.55	....	60.04	80.12	93.07	6.93	31.55	2.37			6,290	1,985	8,275
	1936	2.80	5.89	13.21	33.04	60.46	84.26	[illegible]	4.81	6.02	2.60	.23	.86	7,442	448	7,890
Valley total	1927	....	9.54	21.69	....	59.32	79.56	93.85	6.15	4.56	2.75			124,559	3,761	[illegible]
	1936	11.12	38.81	84.45	95.75	98.21	99.19	99.81	.19	4.04	5.69	2.94		115,323	[illegible]	[illegible]

NOTE.—Bosque del Apache area not included in totals. Depths for 1936 are from measurements taken in October; those for 1927 are average for 1926–27.

comparison with ground-water conditions of 1936 and gives further information on conditions prior to drainage of the valley. A complete and detailed comparison of the data cannot be made because it was impossible to determine accurately the locations of many of the observation wells of the earlier investigation. In a few areas, however, enough old wells were found to furnish a key for locating the remainder in those areas. One of the areas which was best "covered" with wells in the 1917–22 investigation was that between Albuquerque and Alameda, and a contour map for this area showing the average position of the water table in the period 1918–22 was drawn, based on the data obtained in that period. The outstanding characteristic of this map is the perpendicularity of the contours to the river. It is indicated that in this area there was little movement of ground water into or from the river during the period 1918–22. This condition, if typical for the valley, is of much importance, for it indicates that previous to drainage the amount of ground-water seepage from the river was small. Rough ground-water contour maps of the Belen and Albuquerque divisions for months showing high and low ground-water stages in the period 1918–22, plotted according to locations on the old maps, indicate flat lateral gradients, and the undrained Bosque del Apache Grant shows the same flat lateral gradients today. Typical ground-water profiles across the valley, given in the report of the 1917–22 investigation show average gradients near the river of 0.0006. With a transverse valley coefficient of transmissibility of 50,000 (a figure to which present meager data point), this gradient would indicate a ground-water flow of 0.25 second-foot per lineal mile of river, and if the length of the valley between Pena Blanca and San Marcial is taken as 150 miles, the total seepage from the river on both sides would then have been 75 second-feet, or about 50,000 acre-feet a year.

A tentative opinion as to the amount of ground-water inflow from the borders of the valley prior to drainage can also be formed from the earlier data. The 1918–22 map of the Albuquerque-Alameda area shows that the ground-water contours approach the hillsides only slightly deflected from the perpendicular. The contours in the Bosque del Apache area also approach the hillsides near to the perpendicular, and little flow from the mesas is indicated in this area where control is good. The general average of water-table gradients from the mesa to the flood plain, as shown by the profiles of the 1917–22 investigation, is 0.00065. This indicates, therefore, about the same flow from the mesas that was indicated as probably coming from the river, that is, about 50,000 acre-feet in the 150 miles between Pena Blanca and San Marcial. This figure might be increased somewhat to allow for concentrated flow near the debouchures of arroyos on which data are scarce, but it does not seem that the aggregate inflow could have exceeded 100,000 acre-feet. The ground-water flow from the mesas is presumably about the same now as it was before the construction of drains. The figure of 100,000 acre-feet per year would represent a flow from the hillsides of about 0.5 second-foot per mile, and this in turn represents about half the minimum accretion to interior

drains per mile as measured in the Isleta-Belen section during the winter of 1936–37 when there was little, if any, irrigation.

If these figures of river and mesa seepage are approximately correct, the much larger apparent loss of water in the valley in former years must have been due chiefly to other causes, and there must have been other and more important sources of water to support the transpiration of native vegetation. Losses from the river other than by seepage were by diversions for irrigation, by evaporation in the river channel to an extent probably greater than now obtains, and by losses suffered through spreading of the water and consequent infiltration during floods. Of these, diversions for irrigation must have been, by far, most important.

Rincon, Mesilla, and El Paso Valleys

Ground-water data for these valleys are very meager and no study of ground-water conditions in them was included in the Rio Grande joint investigation. These valleys comprise the Rio Grande Project, which is well provided with open drains that satisfactorily maintain ground-water levels at the depths below ground surface required to prevent waterlogging and seeping of the lands.

Periodic measurements of the depths to ground water in 55 to 88 wells in Mesilla Valley have been made by the Bureau of Reclamation in every year since 1924. The observations were made and the results were used chiefly to derive the annual increment or decrement of ground water as a necessary factor in computing the annual consumptive use of water in the valley by the inflow-outflow method. The data were made available to the Bureau of Agricultural Engineering and were used by the bureau in its study of the consumptive use of water in Mesilla Valley as reported in part III of this report.

Average depths to ground water in Mesilla Valley as shown by the January observations have been between 9 and 10 feet throughout the period from 1924 to date.

Quality of Water

In the Upper Rio Grande Basin drainage from the irrigation of upper lands returns to the river and is rediverted to lower lands, and this process is repeated many times in the length of river valleys from the upper to lower limits of the basin. Also the major portion of the water supply reaches the river in the upper portions of the basin with very little contribution from downstream tributaries. Under these conditions the salt concentration of the downstream irrigation waters becomes increasingly higher. Quality of water, as well as quantity of water, becomes, therefore, an important consideration, particularly with respect to the waters that are available to the lowest lands in the basin, such as those in the Tornillo unit of the Rio Grande Project and in the Hudspeth District. With higher salinity of the irrigation water, more abundant applications are needed to prevent the accumulation of salts in the soil and resultant deleterious effects upon plant growth.

In view of these conditions, a comprehensive investigation of the quality of water was made a part of the Rio Grande joint investigation. Samples of water for analysis were taken at frequent intervals from streams, drains, and ground water throughout the basin. These samples were taken under the supervision of the Geological Survey by the field men and members of other agencies cooperating in the investigation. The analyses were made by the Geological Survey, the means employed consisting of conductance tests at field laboratories at Albuquerque and Alamosa, and complete determinations at Washington. Assembly and compilation of the analytical data, together with the summarization and interpretation of them, were done by the Bureau of Plant Industry. A cooperative quality-of-water investigation confined chiefly to conditions along the main stem of Rio Grande had been conducted since 1930 by the Bureau of Plant Industry, Bureau of Reclamation, Geological Survey, International Boundary Commission, and the Colorado State Engineer. The data obtained by this earlier investigation were also assembled by the Bureau of Plant Industry and included with those of the 1936 investigation. The interpretive digest by the Bureau of Plant Industry is included in this report as part IV. The more detailed analytical data are published separately. In the following paragraphs data and results of the investigation as given in the interpretive report are summarized.

The Rio Grande from Del Norte to Fort Quitman

Total yearly quantities and weighted mean concentrations of salts in the water of Rio Grande passing the nine principal gaging stations from Del Norte to Fort Quitman are given in tables 50, 51, and 52. Table 50 gives the 1936 data for all nine stations; table 51, the means for 3 years, 1934–36, for Lobatos, Otowi Bridge, and San Marcial; and table 52, the means for 6 years 1931–36, for the five stations from Elephant Butte Dam to Fort Quitman. These tables indicate clearly the progressive increase in total salt concentration of the river water from the upper to the lower limits of the basin. In 1936, the mean concentration ranged from 0.11 ton of salt per acre-foot of water at Del Norte to 2.84 tons per acre-foot at Fort Quitman. The latter figure is equivalent to approximately 2,100 parts per million. As shown in both tables 50 and 51, a pro-

gressive increase in the total tonnage of salts carried occurs from Del Norte to San Marcial. Below San Marcial there is little change through the reservoir and then, as shown by the 6-year means of table 52, there is a small increase in tonnage to Leasburg Dam, a slight decrease to El Paso, a decided decrease to Fabens, and a smaller one to Fort Quitman. In the period 1931–36 the river has apparently lost 147,000 tons of salts annually between Elephant Butte Reservoir and Fort Quitman. There was, however, an annual gain of 18,000 tons between the reservoir and El Paso, so that between the latter station and Fort Quitman there was an annual loss of 165,000 tons of salts. In comment on this the report of the Bureau of Plant Industry states:

> It is obviously not to be inferred that all of the dissolved solids shown to be lost from the stream between those two points are deposited in the soils of the El Paso Valley division. The data available do not appear to warrant definite quantitative conclusions as to where these dissolved solids are deposited. But painstaking consideration of the available data and reviewing of the computations by which the summaries have been obtained leads to the belief here stated; namely, that there is a very substantial quantity of soluble solids deposited annually somewhere along the Rio Grande between El Paso and Fort Quitman.

It is to be noted not only that the quantities of total dissolved solids passing the stations differ greatly but also that the quantities of each constituent differ even more, so that the composition of the dissolved solids changes appreciably from station to station. Probably the most striking of these changes is the progressive increase downstream in the quantity of the chloride constituent. For 1936, the only year for which data are available for all nine stations, the quantity of chloride increased from 2,800 tons at the Del Norte station to 137,000 tons at the Fort Quitman station. The increase in sodium, from 4,000 tons to 92,000 tons, was also large.

The San Luis Section.

With respect to the waters of San Luis Valley, the data show that the tributary streams contain relatively very little dissolved material. The water leaving the valley in Rio Grande seldom contains more than half a ton of salts per acre-foot and frequently less than a quarter of a ton. The water in the drains north of the river is also of relatively low salinity. Two stations on San Luis Lake showed conductances ranging from 64 to 108. In some of the drains south of the river the salinity is relatively high and doubtless from this area most of the salt is derived that the river carries out of the valley. Data on the ground waters indicate that those around the margins of the valley are of low salinity with low sodium percentages, being similar in character to the inflowing surface waters. In the lower sections of the valley there are two areas in which the shallow

TABLE 50.—*Totals and weighted mean concentrations of salts in* [illegible]

Item	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
River discharge, in 1,000-acre-feet units	[illegible]	281	1,072	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	150
Dissolved solids, in 1,000-ton units	52	71	[illegible]	[illegible]	590	[illegible]	[illegible]	433	[illegible]
Concentrations:									
Tons per acre-foot	0.11	0.26	0.33	0.75	0.79	[illegible]	1.18	1.93	[illegible]
Conductance, $K \times 10^5$ at 25° C	8.5	26.5	30.5	79.4	[illegible]	91.5	129.9	245.2	332.0
Sum, milliequivalents	2.27	5.71	[illegible]	17.31	17.87	19.23	27.28	[illegible]	[illegible]
Constituents, in 1,000-ton units:									
Calcium (Ca)	7.2	[illegible]	[illegible]	88.7	76.3	76.3	63.8	42.1	38.8
Magnesium (Mg)	2.1	2.7	12.2	18.2	15.9	15.5	13.3	10.2	9.3
Sodium (Na)	[illegible]	[illegible]	30.2	98.2	90.8	91.1	103.4	87.0	92.5
Bicarbonate (HCO_3)	13.7	18.0	91.1	[illegible]	82.3	81.0	69.8	38.1	24.8
Sulphate (SO_4)	9.7	18.3	89.8	232.7	232.2	220.7	187.8	121.0	99.3
Chloride (Cl)	2.8	3.9	[illegible]	66.0	[illegible]	64.5	91.1	105.3	136.9
Nitrate (NO_3)	.2		.9	.8	1	1.5	[illegible]	.7	.8

[1] Discharge is sum of diversion to Tornillo Canal and River flow at Tornillo Bridge. Samples taken at head of Tornillo Canal.

TABLE 51.—*Annual totals and weighted mean concentrations of salts in the Rio Grande at 3 control stations above Elephant Butte Reservoir; means for 1934 to 1936, inclusive*

Item	Gaging and sampling stations: Lobatos	Otowi Bridge	San Marcial
River discharge, in 1,000-acre-feet units	247	851	714
Dissolved solids, in 1,000-ton units	67	293	591
Concentrations:			
Tons per acre-foot	0.27	0.34	[illegible]
Conductance, $K \times 10^5$ at 25° C.	27.9	31.8	97.2
Sum, milliequivalents	5.84	7.76	18.63
Constituents, in 1,000-ton units:			
Calcium (Ca)	[illegible]	51.1	[illegible]
Magnesium (Mg)	2.4	9.3	16.2
Sodium (Na)	7.6	26.8	87.0
Bicarbonate (HCO_3)	16.3	80.9	90.4
Sulphate (SO_4)	16.3	71.6	214.6
Chloride (Cl)	3.6	11.9	57.4
Nitrate (NO_3)	[illegible]	1.1	1.1

TABLE 52.—*Annual totals and weighted mean concentrations of salts in the Rio Grande at 5 control stations below Elephant Butte Reservoir; means for 1931 to 1936, inclusive*

Item	Gaging and sampling stations: Elephant Butte outlet	Leasburg Dam	El Paso (Courchesne)	Fabens-Tornillo[1]	Fort Quitman
River discharge, in 1,000-acre-feet units	766	745	523	257	172
Dissolved solids, in 1,000-ton units	[illegible]	647	[illegible]	496	475
Concentrations:					
Tons per acre-foot	.81	.87	1.22	1.93	2.75
Conductance $K \times 10^5$ at 25° C	87.1	91.0	127.2	212.0	295.7
Sum, milliequivalents	18.32	[illegible]	28.71	45.51	65.81
Constituents, in 1,000-ton units:					
Calcium (Ca)	78.3	81.8	70.3	47.8	40.8
Magnesium (Mg)	17.0	17.9	15.5	11.4	10.0
Sodium (Na)	96.6	104.0	124.3	[illegible]	111.6
Bicarbonate (HCO_3)	94.4	95.8	81.4	46.9	28.5
Sulphate (SO_4)	234.7	239.0	210.1	135.3	107.2
Chloride (Cl)	56.7	72.4	112.7	126.8	160.9
Nitrate (NO_3)	.3	1.3	1.7	[illegible]	[illegible]

[1] Discharge is sum of diversion to Tornillo Canal and river flow at Tornillo Bridge. Samples taken at head of Tornillo Canal.

TABLE 53.—*[illegible] riverside and interior drains of Middle Rio Grande Conservancy District, N. Mex., 1936*

[illegible]	[illegible]		
	[illegible]	[illegible] drains	Interior drains
[illegible]	[illegible]	[illegible]	88.5
[illegible]	53.2	[illegible]	163.0
[illegible]	[illegible]	110.7	155.0

TABLE 54.—*Salinity of ground waters of the Middle Rio Grande [illegible] [illegible]*

[illegible]	[illegible] Conservancy District		
	Albuquerque	Belen	Socorro
[illegible]			
Conductance tests only:			
[illegible]	[illegible]	[illegible]	70
[illegible]	158	[illegible]	[illegible]
[illegible]			
[illegible]	35	[illegible]	20
[illegible]	[illegible]	[illegible]	319
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	13	[illegible]	[illegible]
[illegible]			
[illegible]			
[illegible]	11	11	12
[illegible]	74	[illegible]	[illegible]
[illegible]	32	[illegible]	[illegible]
[illegible]	11	19	[illegible]

or subsoil waters are generally rather saline. Toward the middle of the valley the deeper water is generally "soft"—i. e., it has a high sodium percentage—and in the area north of the eastern edge of the Rio Grande delta the deeper waters are both soft and rather saline.

The Middle Section

The waters contributed by tributary streams of the Middle section above Galisteo Creek on the east side are of low salinity, with conductances ranging from 5 to 72. Those of Rio Chama are likewise of low salinity, with conductances less than 80. The low-water discharges of Jemez Creek, Rio Puerco, and Rio Salado are comparatively saline, with conductances ranging up to 400 or more. The dissolved salts carried by these 3 streams consist largely of sulphates of calcium, sodium, and magnesium. Comparison of the mean conductance of the irrigation water and of that in the riverside and interior drains of the Middle Rio Grande Conservancy District as found in 1936 is shown in table 53. There is a progressive increase southward in the salinity of the irrigation and riverside drain water, but not in the interior drain water between Belen and Socorro divisions. This exceptional situation with respect to the interior drain water probably is accounted for by the fact that the Socorro division is narrow and its interior drains are in a position to receive more direct seepage from the river than do those in other divisions. A summary of the data on the salinity of ground water in the Middle Valley is given by table 54.

The Elephant Butte-Fort Quitman Section

The total quantities and mean concentrations of salts in the drain waters of the Rincon, Mesilla, and El Paso divisions of the Rio Grande project are shown in table 55. The similar quantities for the river water at the stations above and below each division are also shown for purposes of comparison. The data are derived from the detailed analyses made in the period 1929-36, and they represent mean values for that period. Summarizing the conditions as shown by table 55, the river brings into the area annually from Elephant Butte Reservoir about 766,000 acre-feet of water carrying about 620,000 tons of dissolved solids. It takes away from the area, past Fort Quitman, about 172,000 acre-feet of water carrying about 473,000 tons of dissolved

TABLE 55.—*Totals and mean concentrations of salts in river and drain water of divisions of Rio Grande Project, New Mexico and Texas; means for 1930-36*

Divisions	[illegible]		[illegible]		[illegible] [1]					
	[illegible] feet	Total dissolved solids tons	Conductance	Total dissolved solids tons [illegible]	Ca	[illegible]	[illegible]	[illegible]	SO_4	Cl
[illegible]	[illegible]	[illegible]	87	0.81	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17
[illegible]	[illegible]	[illegible]	109-142	1.32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23-28
[illegible]	745,000	647,000	[illegible]	.87	41	11	[illegible]	[illegible]	49	[illegible]
[illegible]	205,000	383,000	108-442	1.87	17-44	10-15	[illegible]	15-37	32-43	[illegible]
[illegible]	523,000	638,000	127	1.22	35		[illegible]	[illegible]	43	[illegible]
[illegible]										
Totals of 7 drains above Fabens	[illegible]	331,000	180-419	4.15	[illegible]	10-13	51-63	13-23	[illegible]	[illegible]
Tornillo drain (4 drains tributary)	[illegible]	243,000	299-945 517	[illegible]	[illegible] 32	7-12 9	[illegible]	5-16	17-30 22	[illegible] 69
Division totals	133,000	574,000	[illegible]	4.32	[illegible]	7-13	51-66	5-23	[illegible]	35-76
[illegible]	172,000	473,000	[illegible]	[illegible]	[illegible]	11	[illegible]	[illegible]	[illegible]	[illegible]

[1] Percent of sum of milligram equivalents of cations for calcium, magnesium, and sodium and of sum of milligram equivalents of anions for bicarbonate, sulphate, and chloride.

solids. Between these two stations on the river the irrigation and drainage of the contiguous agricultural lands results not only in changing the concentration of the dissolved solids of the stream waters but also in changing, and appreciably, the composition of those dissolved solids. The change of concentration is upward at successive stations along the stream and it is accompanied by higher concentrations in the drain waters and in the subsoil waters as sampled from observation wells. The changes in composition are in the direction of higher percentages of sodium and of chloride, with lower percentages of the other four major constituents.

TABLE 56.—*Salinity of ground water in observation wells and contiguous drains in divisions of Rio Grande Project, New Mexico and Texas, 1936*

Division	Salinity in terms of conductance $K \times 10^5$ at 25° C.			
	Observation wells		Drains	
	Number sampled	Mean conductance	Number sampled	Mean conductance
Rincon	4	200	4	145
Mesilla	16	237	7	206
El Paso				
Above Fabens	11	705	3	448
Below Fabens	44	570	3	497

The salinity of ground waters in the divisions of the Rio Grande Project, as indicated by conductance determinations of well samples taken in 1936, is shown in table 56. The mean conductance of water of the drains contiguous to the observation wells, as derived from samples taken during the same period as that in which the well samples were taken, is also shown for comparison.

Control of Salinity

In the problem of high concentration of salts in the irrigation water and the conditions under which such water may be used without harmful effects on plant growth, the controlling factor to be considered is the concentration of the soil solution within the root zone of the plants. When irrigation water is applied to land, some of the water, usually the major portion of it, is evaporated from the soil or transpired by plants, chiefly the latter. The surplus, if any, passes away either by downward percolation, or by moving laterally as subsoil drainage. Because of the losses by evaporation and transpiration, the residual water becomes more concentrated with soluble material. Thus the "soil solution" in irrigated land is normally more concentrated than the water with which the soil is irrigated, but the degree of greater concentration depends upon what proportion of the water applied to the soil surface ultimately percolates through the root zone and escapes below. As the proportion of the volume of root-zone percolation to the volume of water applied increases, the difference between the concentration of the soil solution and that of the irrigation water diminishes. Consequently, if injurious concentrations of salinity in the soil solution are to be avoided, more irrigation water must be applied if it is highly saline than would be needed if it were less saline. Hence, as a practical consideration in the control of salinity, a definite determination is needed of the application of irrigation water required in order that a given concentration of the soil solution shall not be exceeded.

The essential elements in this problem are listed in the report of the Bureau of Plant Industry. They include:

(1) Consumptive use, i. e., the quantity of water, in depth per unit area, required to support crop growth and meet evaporation losses.

(2) Irrigation requirement; i. e., the quantity of water, in depth per unit area, required, not only for consumptive use, but also to provide sufficient percolation through the root zone to keep the concentration of the soil solution below a given maximum.

(3) Concentration of the irrigation water either in respect to total dissolved solids or in respect to any constituent regarded as potentially most likely to cause trouble.

(4) Concentration of the soil solution in the root zone, measured by the same standards, or as to the same constituent as used for the irrigation water.

Several equations have been developed to express the relationship between these elements, but as the quantitative factors involved are yet somewhat indefinite, it has been considered best, in this report, to proceed more or less arbitrarily in assuming allowances to maintain the desired salt balance. The basis on which these allowances have been assumed appears later in this report in connection with consideration of water uses and requirements.

PART I
SECTION 3.—IRRIGATION DEVELOPMENT

History of Development

Recorded history of the Rio Grande Valley begins with its discovery by the Spanish explorers under Coronado in 1540. As reported by his expedition, Indians were living in pueblos in what is now known as the Middle Valley in New Mexico, cultivating land and bringing water to it by irrigation ditches as their ancestors long had done. An outline of the early development of irrigation is given by Follett in his 1896 report to the International Boundary Commission, as follows:

Before the middle of the sixteenth century the Spaniards entered New Mexico and the valley of the Rio Grande and there found the Pueblo Indians, living in their many-storied towns and cultivating the land of the valleys, bringing water onto it by acequias, or irrigating ditches, many of which are still in use to this day. How long these Indians had been on the ground is unknown, but they were even then old inhabitants, and raised not only grain and fruit, but even flowers, as one poetical and doubtless homesick Spaniard wrote that roses bloomed along the acequia bank "as bloomed the roses of beautiful Aragon." There are some 17 or 18 of these settlements of Pueblo Indians in New Mexico, each holding a land grant 2 leagues square and each with its own pueblo, containing from 200 to 600 people. There were at least this number of pueblos when the Spaniards came to the country, and probably several more, as the ruins of three or four still exist. The inhabitants of each pueblo were then much more numerous than now. In other words, prior to the middle of the sixteenth century, 350 years ago, there were some 15,000 to 20,000 people living from products raised by irrigation in the Rio Grande drainage above the Jornado del Muerto, and tne area of irrigated land probably exceeded 30,000 acres.

While the Spaniards first entered New Mexico from Sonora and the Gulf of California, the first attempts at colonization were made from El Paso as a base, the Spanish conquest of Mexico having extended to the Rio Grande. This first attempt was made in 1598, and the first Spanish capital of New Mexico was then established at Chamita, in the Espanola Valley, just above the mouth of the Chama. This was abandoned in 1605, and the inhabitants and capital transferred to Santa Fe, where they and their descendants remained until 1680, engaged principally in mining. Then the Pueblo Indians revolted and drove the Spaniards from the country. In 1692 it was reoccupied by the Spaniards and permanently held. Bernalillo was founded about 1700 and Albuquerque in 1706. Settlements were made along the Rio Grande, both in the Albuquerque and Espanola Valleys, and also up the Chama, the Abiquiu grant on the latter stream being made to the inhabitants of that town in 1739. El Rito, some 20 miles northeast of Abiquiu, was occupied in [illegible].

The Mexicans did not penetrate to the San Luis Valley, judging from the water rights there granted, until after 1850, [illegible] 1852. [illegible] years after 1852 the settlements in the San Luis Valley were confined to the country on the Costilla and Culebra and to the Conejos Valley, the town of Conejos being founded in 1855. In 1866 and 1867 settlements were started on the Rio Grande, San Luis, and Saguache, while the next 3 years saw farms opened and small ditches taken out on the Carnero, the La Garita, Alamosa, and La Jara, but all of these, except those at Conejos, were confined to the little valleys back in the hills around the margin of the San Luis Valley proper. On these farms the principal product was hay. This the Mexicans fed in winter to their stock, to which the main valley furnished abundant pasturage for the greater portion of the year.

About 1873 or 1874 the Americans began to move into the San Luis, but still the farm lands were confined to the small side valleys. The first settlement in the San Luis Valley proper, outside of Conejos, was made by the Mormons, who founded Manassa in 1878 or 1879. About this time the Denver & Rio Grande Railroad built into the valley. The main industry was still cattle raising, however, until about 1882. Then commenced the era of large canal building, which continued for 10 years. During this time were built the Rio Grande, Monte Vista, Empire, San Luis Valley, Costilla, Prairie, and Farmers' Union Canals, besides many others. All those named head on the Rio Grande between Del Norte and Alamosa, and, stretching 30 or 40 miles north and south from the river, cover the whole of the western half of the valley with their network of laterals.

The San Luis Section

In the San Luis section, as indicated in the Follett report, irrigation began on Rio Grande tributaries, such as Culebra and La Jara Creeks and Conejos, San Antonio, and Costilla Rivers. Diversions for small ditches could be accomplished more easily from the smaller streams than from Rio Grande. A summary of the decreed water priorities in San Luis Valley to 1871 shows only 36 second-feet on Rio Grande as against 2,054 second-feet on tributaries. Subsequent to the building into the valley of the Denver & Rio Grande Railroad, construction began in 1879 on the Rio Grande Canal, the largest in the valley today. As noted by Follett, this was the forerunner of an intensive development in the following decade during which were built most of the larger canals which are now diverting water from Rio Grande. The great activity in this period is strikingly demonstrated by the fact that decreed water rights bearing dates between 1881 and 1890 total nearly 8,000 second-feet on the streams of the southwest area, Rio Grande, Alamosa, and La Jara Creeks, Conejos and San Antonio Rivers. Substantial development was made also in all other portions of the valley. From 1890 to 1900 development seems to have been confined largely to the area served by Rio Grande, as indicated by decreed rights to nearly

3,000 second-feet that were initiated for this area while little water was decreed in other parts of the valley. The record indicates that development had proceeded at this time to the extent of greatest possible diversion of the natural stream flow and that storage developments were contemplated.

A serious condition soon complicated the situation. It was brought about by the rise in ground-water levels to such an extent that lands in the lower parts of the valley were becoming seeped. With continued large diversions from Rio Grande to the porous and shallow soils in the closed basin, the underground basin had filled rapidly; the water table had risen from depths ranging from 40 feet on the east to 100 feet on the west to a position practically at the surface on the east, bordering the sump, and to a level within 10 to 15 feet of the surface on the west.

Under the large network of canals built between 1880 and 1890, land was first brought in about 8 miles northeast of Monte Vista. Activities were extended from that locality to the north and east until in a short time the whole central portion of San Luis Valley as far north as Hooper became one flourishing wheat field.

A method of subirrigation peculiar to this region was developed and is still practiced as it is claimed to be essential to the successful growth of crops under the soil and water-supply conditions which prevail. By it the ground water is built up to within 1 to 3 feet of the surface and water is then allowed to run slowly through small ditches spaced about 8 rods apart. Water from these ditches seeps outward, supplying moisture to the plants. This method really constitutes in part a substitution of underground storage for "headwater" or stream storage in an effort to adjust the water supply to the irrigation demand. It results, however, in overdiversion during the spring run-off, in unduly high water tables, and in excessive evaporation and transpiration losses.

The rise in ground water and the seeping of lower lands soon began to force abandonment of acreages along the eastern side of the closed basin, with concomitant substitution of lands farther west. This gradual process of abandonment at the east and extension westward proceeded at a rate of half a mile to a mile per year, so that by 1910 or 1915 the once prosperous agricultural areas near Mosca and Hooper were under brush and salt grass, the farm houses abandoned, and the fences broken down. As years went by the irrigated zone shifted to the westward until it reached the extreme west side of the valley, while the broad stretch of once-occupied lands to the eastward was left to revert to its natural state, badly damaged, however, by alkali.

Drainage to reclaim seeped lands in various parts of the valley began about 1911 and by 1921 eight drainage systems serving about 90,000 acres had been constructed. Of these, the Sylvestre, Gibson and Rio Grande are in the closed basin and the Parma, Carmel, McLean, Monte Vista Town, and Norton are in the southwest area. Drainage of the western area in the closed basin has developed waters which have aided in a progressive reoccupation of part of the neighboring lands to the eastward, but large areas between the present irrigated area and the old eastern boundary are still open for reclamation by irrigation and drainage, the only basic requirement being an available water supply.

Decreed water rights initiated in the period 1900 to 1920 total about 3,400 second-feet for the valley. Of these, 1,100 second-feet were for the Conejos-San Antonio area and 1,000 second-feet for the Trinchera area. Since 1920 little water has been decreed. Development has included the works constructed by the Del Norte Irrigation District to irrigated bench lands lying north of Rio Grande between Del Norte and Monte Vista, the dam for the Continental Reservoir and additional drainage systems. The latter include the drains of the San Luis Valley Irrigation District in the closed basin and the systems of the Waverly, Bowen, Morgan, Adams Lane, Manassa Town, and San Luis Valley Drainage District in the southwest area.

Although the development of storage to regulate the water supply for San Luis Valley was considered in the early 1890's, construction on any large scale was prevented by the "embargo" of 1896. This was an order by the Secretary of the Interior directing the Commissioner of the General Land Office to suspend action on all applications for rights-of-way across public lands in Colorado and New Mexico for use of Rio Grande water. It was issued expressly to prevent further depletion of the flow of Rio Grande in the Elephant-Butte-Fort Quitman section, and as a result of complaints by Mexico of water shortages and the subsequent investigation and report by Follett to the International Boundary Commission. This departmental order held until 1907, when it was modified to permit approval of applications for rights-of-way involving the diversion of storage of water in amounts not exceeding 1,000 acre-feet and of applications in connection with which there might be a showing that the rights of the applicants had been initiated prior to the beginning of active operations, on March 1, 1903, as stated, by the Reclamation Service for the Rio Grande Project. With this modification the embargo remained in effect until 1925, when it was lifted entirely.

Most of the reservoir development in the San Luis section that could be accomplished under the embargo took place between 1900 and 1915. The Rio Grande

and Santa Maria Reservoirs in the upper Rio Grande watershed, with a combined capacity of about 93,000 acre-feet, were completed in 1913. La Jara and Terrace Reservoirs on La Jara and Alamosa Creeks were completed in 1910 and 1912, respectively. These have a combined capacity of about 32,000 acre-feet. Other reservoirs completed in this period include the Sanchez on Culebra Creek and Mountain Home and Smith on Trinchera Creek. The Continental Reservoir in the upper Rio Grande drainage, capacity 27,000 acre-feet, was completed in 1928.

Acreage irrigated.—For administrative purposes of the Colorado State engineer in distribution of the surface waters in accordance with rights decreed by the courts, the San Luis section comprises irrigation division no. 3 subdivided into eight water districts, nos. 20, 21, 22, 24, 25, 26, 27, and 35. The positions and approximate boundaries of these districts are shown on plate 1. The irrigation division is administered by a division engineer and each water district by a water commissioner reporting to the division engineer. These officials distribute the available water supply according to the various decrees and render weekly reports of the amount of water distributed, the latest priority receiving water, and other pertinent data. The division engineer makes an annual report embodying data on the ditches, reservoirs, quantity of water diverted, storage operations, acreage and crops irrigated, operation and maintenance costs, and the general conditions which have prevailed during the year. Except for Federal census data and the reports of a few surveys made in connection with engineering investigations, these reports of the division engineer have been the only available source for deriving the total acreage irrigated in the valley in the past. Such checks as could be made of the data on irrigated acreage in these reports indicate that they may be more or less inaccurate. This may be attributed in part to differences in interpretation of what areas were actually irrigated, involving, for example, the question as to whether or not certain extensive acreages of pasture were irrigated, but in the main it is attributable to the conditions and methods under which the data are obtained by the water commissioners. They do not make an actual survey, but rely upon information furnished by the water users. In general, the data from the water commissioner's reports appear to give totals higher than the actual irrigated acreage. Regardless of whether these data represent correct totals for each year, it is believed that they may be used to furnish an index of the trend of irrigation in the valley. In a report on "Investigations in the Middle Rio Grande Valley" submitted in 1932 by E. H. Debler, hydraulic engineer of the Bureau of Reclamation, the annual data on the irrigated acreage in San Luis Valley as given by the water commissioner's reports were compiled by water districts for the period 1880 to 1930. This compilation has been reproduced, with the addition of data for the years 1931 to 1935, as table 57 of this report.

In the period 1925–34 four special field surveys were made of the irrigated acreage in San Luis Valley. The first was made in 1925–26 by R. J. Tipton for the Colorado State engineer. The other three were made in connection with investigations by the New Mexico State engineer; in 1927 by E. P. Osgood; in 1932 by J. H. Bliss; and in 1934 by Russell Dallas. The data of these surveys are shown in table 58.

The Middle Section

Follett's historical outline previously quoted furnishes some information on the beginning of agricultural and irrigation development in the Middle Valley. A more detailed account of events during the Spanish occupation of significance in tracing irrigation development is given in the 1928 report to the Middle Rio Grande Conservancy District by J. L. Burkholder. The following statements are quoted from pages 23 to 25 of that report:

> The first Spaniards to visit New Mexico were treasure seekers under Coronado. They accomplished little in the way of developing the country and, disappointed in their quest for the fabulous wealth of "Cibola", returned to Mexico in 1542.
>
> It was not until 1598 that a real colonizing expedition under Don Juan de Onate came into the valley and founded a settlement near the mouth of the Rio Chama at the Indian pueblo of Yugewinge. This settlement was christened San Juan de los Caballeros and was the first capital of the new empire. Here, with the assistance of 1,500 Indians, Onate built a canal or "acequia" which was probably the first Spanish ditch in the country.
>
> A few years later (probably 1609) this settlement was abandoned and a new capital was established at the Cuidad Real de la Santa Fe de Francisco de Assizi, where it remains today under the short name of Santa Fe.
>
> Exploration and colonization were carried on from Santa Fe for a period of about 75 years, but in 1680 the Indians rose in revolt and drove the Spaniards out of the country. They retired to Paso del Norte (the El Paso of today) and remained there for 12 years. In 1692, under Don Diego de Vargas, they put down the Indian rebellion and returned to Santa Fe and the Rio Grande valley.
>
> At this time many vast Spanish land grants were made, in recognition of services rendered during the pueblo rebellion, and the real development of the country began. Perhaps because of the location of Santa Fe, which was the capital and headquarters for the entire country, this development took place generally from north to south, the country near Santa Fe being settled first.
>
> In almost regular progression down the river to the south, settlement and development followed. Bernalillo was founded about 1700 on a land grant from the Spanish Crown.
>
> The Villa de San Felipe de Albuquerque, named for King Philip of Spain and his cousin, the Duke of Albuquerque, was settled in 1706 on the site of the old hacienda of Don Luis Carbajal which had been destroyed by the Indians during the uprising of 1680.
>
> In 1739 certain residents of Albuquerque, dissatisfied with conditions there, moved a few miles to the southward and established the settlement known as Nuestra Senora de la Conception

TABLE 57.—*Acreages irrigated in San Luis Valley, as derived from water commissioner's reports*

Year	Water districts								Total irrigated
	No. 20	No. 21	No. 22	No. 24	No. 25	No. 26	No. 27	No. 35	
1880	[illegible]	[illegible]	[illegible]	[illegible]	34,100	[illegible]	[illegible]	[illegible]	131,475
1881	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17,270	[illegible]	[illegible]	[illegible]
1882	[illegible]	[illegible]	[illegible]	8,700	35,950	[illegible]	[illegible]	[illegible]	165,085
1883	56,315	[illegible]	44,400	[illegible]	36,810	18,725	4,000	[illegible]	[illegible]
1884	[illegible]	22,000	45,400	8,800	39,120	20,380	[illegible]	2,670	[illegible]
1885	51,935	24,000	51,700	8,800	39,450	[illegible]	[illegible]	2,670	213,210
1886	[illegible]	[illegible]	56,400	8,800	39,930	21,230	4,000	2,890	228,595
1887	72,675	38,200	[illegible]	8,800	40,950	22,210	4,000	2,890	247,125
1888	88,630	42,000	59,400	[illegible]	[illegible]	22,505	4,000	4,010	272,975
1889	97,535	42,000	60,000	8,800	45,950	22,505	4,000	4,520	285,310
1890	112,480	44,000	[illegible]	10,000	45,950	22,505	[illegible]	4,780	303,715
1891	[illegible]	46,000	55,000	10,000	[illegible]	[illegible]	[illegible]	4,780	354,440
1892	216,685	45,000	50,000	10,000	47,550	20,290	4,000	4,780	[illegible]
1893	179,785	44,000	45,000	[illegible]	46,200	19,160	4,000	4,780	352,925
1894	166,085	[illegible]	50,000	10,000	44,750	18,020	4,000	4,780	339,635
1895	164,795	41,550	[illegible]	9,500	42,940	16,550	4,040	4,430	339,105
1896	139,795	37,940	60,525	7,050	46,295	20,205	2,670	4,180	318,760
1897	162,229	[illegible]	[1] 60,000	[illegible]	45,408	12,360	4,586	[1] 4,500	335,211
1898	134,277	[illegible]	[illegible]	10,537	[illegible]	19,857	[illegible]	[1] 4,000	269,216
1899	[illegible]	[1] 45,000	[1] 50,000	10,637	44,591	3,755	1,569	[illegible]	361,096
1900	[illegible]	58,934	[1] 55,000	10,541	46,098	23,606	[illegible]	[illegible]	412,829
1901	[illegible]	17,600	[1] 60,000	10,528	[illegible]	23,658	2,000	10,000	426,472
1902	96,920	22,342	[1] 30,000	11,067	14,519	5,155	1,303	6,245	187,551
1903	[2] 175,000	30,121	43,920	11,045	43,075	11,275	3,230	[1] 6,000	323,666
1904	126,234	14,412	[1] 35,000	6,739	16,141	5,479	3,531	[1] 4,000	211,536
1905	232,246	28,456	[1] 70,000	8,407	[1] 15,000	16,143	2,585	[1] 5,000	377,837
1906	249,931	31,000	73,004	16,655	16,180	20,116	1,555	[illegible]	413,441
1907	[illegible]	30,675	74,798	17,068	26,797	24,273	1,801	11,900	454,369
1908	[illegible]	38,485	66,730	16,800	25,338	14,275	1,532	[1] 5,000	444,259
1909	[illegible]	31,942	104,748	20,412	[3] 22,744	25,021	4,282	[illegible]	421,451
1910	248,097	34,146	93,442	35,910	20,281	24,709	5,397	3,478	465,460
1911	247,077	61,732	87,524	[illegible]	[illegible]	25,694	4,241	4,700	468,998
1912	271,656	[illegible]	117,081	13,846	17,604	29,396	6,250	[illegible]	519,789
1913	251,752	61,009	97,951	15,226	18,936	28,499	5,452	[1] 10,000	[illegible]
1914	[illegible]	51,444	85,730	15,294	19,600	31,636	6,025	16,928	526,944
1915	[illegible]	50,842	88,365	12,627	26,011	30,932	4,244	20,060	513,361
1916	304,271	55,140	98,760	12,945	21,218	27,920	4,132	12,535	536,921
1917	[illegible]	44,212	97,555	29,908	15,991	37,765	4,208	14,820	561,334
1918	225,446	40,140	97,040	10,516	22,151	26,575	2,146	11,776	435,790
1919	310,259	38,669	101,457	25,928	23,511	37,527	4,766	16,058	558,175
1920	329,561	41,387	99,760	13,799	21,810	37,222	7,604	16,401	567,544
1921	325,249	39,858	89,420	22,347	40,609	53,057	5,100	[illegible]	616,442
1922	342,148	42,196	99,270	17,904	21,035	35,127	6,740	24,349	588,769
1923	379,349	41,821	135,365	16,794	9,650	45,583	5,229	8,943	642,734
1924	337,767	40,806	136,840	31,987	22,278	19,766	8,195	17,539	615.178
1925	334,581	44,537	128,180	31,536	17,776	46,763	6,827	11,640	621,836
1926	356,904	47,003	117,038	32,423	[3] 32,267	50,320	5,902	11,707	653,564
1927	452,568	55,984	106,863	33,203	62,216	47,802	5,485	15,550	779,671
1928	370,098	61,146	103,390	33,811	63,866	49,067	7,546	14,211	703,135
1929	403,772	53,859	104,368	34,645	49,418	58,067	7,158	25,190	736,477
1930	426,340	43,920	102,050	[illegible]	34,245	44,682	6,696	28,871	722,393
1931	325,249	39,858	89,420	22,346	40,609	53,507	5,100	40,802	616,891
1932	412,984	57,297	87,104	30,886	47,116	30,918	5,752	33,730	705,787
1933	409,313	44,647	86,831	32,400	26,573	25,376	6,074	29,720	660,934
1934	378,494	38,737	92,477	30,686	26,946	44,944	6,241	20,241	[illegible]
1935	389,709	45,810	107,833	30,614	27,372	66,960	8,403	22,323	699,024

[1] Estimated to complete total for the division.

[2] Available records showing approximately 57,000 acres for district 20 in this year are believed to be incomplete. The figure given is an estimate based on general conditions applying in the year.

[3] Published figures are higher by 60,000 acres in 1909 and by 30,000 acres in 1926 because of the inclusion of pasture land on the Baca grant. For other years, subsequent to 1903 at least, figures for such pasture lands are not included.

Data for 1880 to 1896 are from the Follett report, S. Doc. 229, 55th Cong., 2d sess., but were largely supplied to Follett by San Luis Valley water commissioners. Other data except as noted are from biennial reports of the Colorado State engineer or from reports of the division engineer, irrigation division no. 3.

de Tome Dominquez. This settlement still exists under the shorter name of Tome, and it is interesting to note that one of the reasons for the dissatisfaction of the original settlers with Albuquerque was the shortage of water for their fields.

In 1716 a grant of land known as the San Clemente Grant was made to Ana Snadoval y Manzanares, daughter of Mateo Sandoval y Manzanares, one of the original colonists driven out by the pueblo rebellion of 1680. The present town of Los Lunas, some 20 miles south of Albuquerque, is located on this grant.

The Belen area developed from another land grant made in about 1642 and the La Joya Grant to the south followed.

The Socorro area was developed many years later. There were Indian pueblos in this locality in pre-Spanish time and the Spaniards established several missions at these pueblos, but after the rebellion of 1680 these few small settlements were exposed to continual attack by the hostile Apaches, who murdered or drove off the settlers, and it was not until the building of the railway down the Rio Grande Valley some 200 years later that the real development of this country took place.

TABLE 58.—*Irrigated area, San Luis Valley, Colo., reported by surveys of Tipton, Osgood, Bliss, and Dallas*

Authority	Year of survey	Irrigated area in acres
Tipton	[illegible]	494,200
Osgood	1927	507,471
Bliss	[illegible]	[illegible]
Dallas	1934	[1] 428,737

[1] 70,184 acres irrigated in 1932 were not irrigated in 1934 because of water shortage

As each community was settled it built its own irrigating ditch or "acequia", since all of these settlements were agricultural communities, dependent upon irrigation, without which no crops could be grown in this country.

From the date of discovery by the Spanish Conquistadores in 1539, the Middle Rio Grande Valley was claimed by Spain and was ruled by Spanish governors under the jurisdiction of the

colonial government of Mexico until 1821, when Mexico estab- [illegible]

When Mexico revolted and became independent, this upper country became Mexican territory and so remained until it was ceded to the United States of America under the treaty of Guadalupe Hidalgo in 1848. This treaty, which marked the end of the Mexican War, guaranteed to the inhabitants of the ceded area the same rights and privileges to which they had been accustomed. Consequently the customs of the Spanish colonies have been preserved to a considerable extent in New Mexico.

Information on the development and extent of irrigation in the Middle section prior to Follett's investigation, and indeed even to 1918, is meager. As described further under the heading of acreage irrigated, estimates by New Mexico engineers fix a peak development about 1880, with a sharp decline from that date to 1896. Subsequently a further but more gradual decline is indicated to about 1925. This decline is attributed to a progressive increase in seeped and water-logged areas which, at the time of organization of the Middle Rio Grande Conservancy District in 1925, occupied almost two-thirds of the agricultural area later incorporated in that District. The seeped condition is claimed to have been the result of decreased flow in Rio Grande which caused deposition of silt and a consequent raising of the river bed and of the contiguous water table. The decrease in river flow is asserted to have been due in part to depletions in San Luis Valley.

As early as the late 1890's it was realized by many people in the Middle Valley that drainage and an improved irrigation system were necessary, and some years later a small drainage district was attempted south of Albuquerque. However, these early attempts at reclamation were unsuccessful, due, partly, to lack of proper organization. In 1923 the Legislature of New Mexico passed a conservancy act and the decree of organization of the Middle Rio Grande Conservancy District was entered by the appropriate court on August 26, 1925. The plan of the district for flood control, drainage, and irrigation in the Middle Valley was approved in 1928, and active construction began in 1930. Completion of the works, including El Vado reservoir on Rio Chama, with a capacity of 198,000 acre-feet, was accomplished in 1935.

Acreage irrigated.—As reported by Follett in 1896, there were at that time on Rio Grande and its tributaries in New Mexico above San Marcial, 572 ditches having a total capacity of 5,106 second-feet and conducting water to 150,410 acres. Of the total, 104,650 acres were irrigated from tributaries of Rio Grande and 45,760 from the main stream. The main stream acreage involved 14,060 acres in Espanola Valley and 31,700 acres from Cochiti to San Marcial.

The next available information on irrigated acreages in the Middle section is given in a report by Herbert W. Yeo to the Bureau of Reclamation, covering the results of an investigation made by him in 1910. The following data are derived from this report:

[illegible]	Acres
Rio Grande tributaries above San Marcial	60, 390
Soccoro Valley	10, 060
Lower Albuquerque Valley	22, 860
Upper Albuquerque Valley	12, 300
Espanola Valley	5, 335
Total	110, 945

The Follett and Yeo acreage and ditch data for the Middle Valley unit from Cochiti to San Marcial show:

Year	Number of ditches	Capacity, [illegible]	[illegible]	Authority
[illegible]	71	1, 779	31, 700	Follett.
1910	[illegible]	[illegible]	[illegible]	Yeo.

During 1918 the New Mexico State engineer completed a survey of the valley from Cochiti to San Marcial as a preliminary to drainage. The following statements are quoted from the report of this survey:

The total gross area of the valley, as determined by the survey, including all areas from the foot of the slopes as nearly as may be determined, is 206,012 acres, classified as follows:

	Acres
Cultivated (class I)	40, 063
Cultivated (class II)	8, 732
Alkali and salt grass	[illegible]
Swamp	6, 517
Timber	[illegible]
River and river wash	27, 536
Other valley	33, 593
Total	206, 012

In cultivated (class I) of this classification are included all areas that are being cultivated and, by a superficial examination, do not show that crops are being impaired by a too high water table. It does not mean that the land is not suffering from a high water table or even endangered, nor that it will grow all crops without injury, but that there are no surface indications of a shallow soil.

In cultivated (class II) are included those cultivated areas which do show indications of a high water table either by evident saturated soil or the presence of alkali or by affected crops.

In alkali and salt grass are included those areas which are not being farmed, have visible quantities of alkali, or are overgrown with salt grass. It is usual that such areas have the water table within a very few inches of the surface and during periods of high water table it may be at, or even above, the ground surface.

The swamp areas are those that have the ground water exposed and are indicated by the water surface, marsh and rushes. This class is very closely related to alkali and salt grass areas as the two may oscillate to a certain extent with fluctuations of the ground water within the same year or from year to year.

The timbered areas are those overgrown with timber or brush, usually cottonwoods, willows, or thorn bushes.

In the river and river wash areas are those actually occupied by the river or the washed channels through which the water flows at a higher river stage. These latter are usually free from vegetation and consist of washed sand or gravel.

In the other valley areas are included all lands that do not come under the other classifications and may be sand washes or sand dunes or sage brush either above or below ditches, and village or town areas.

This report indicates that there were found in the Middle Valley area covered, 65 ditches with a carrying capacity of 1,957 second-feet.

Between 1924 and 1928 investigations in Rio Grande tributary areas were made by the New Mexico State engineer's office, and the Middle Valley area from Cochiti to San Marcial was under investigation by engineers of the Middle Rio Grande Conservancy District. From the data of these investigations it appears that in 1928 or thereabouts the irrigated acreage was approximately as follows:

Valley subdivision:	Acreage irrigated [illegible]
Rio Grande tributaries above San Marcial	91, 760
Middle Valley-Cochiti to San Marcial	45, 580

The 1928 Burkholder report of the Middle Rio Grande Conservancy District shows for 1927 a total of 67 ditches, with a carrying capacity of 2,038 second-feet, in the Cochiti-San Marcial area.

A summary of the foregoing data with respect to the acreage irrigated is given in table 59.

TABLE 59.—*Irrigated acreages in the Middle section comprising the Rio Grande drainage area in New Mexico above San Marcial*

Year	Acreage irrigated					Authority
	Tributary areas	Rio Grande			Total above San Marcial	
		Espanola Valley	Cochiti to San Marcial	Total		
1896	[illegible]	14, 060	31, 700	45, 760	150, 410	W. W. Follett.
1910	60, 390	5, 335	45, 220	[illegible]	110, 945	H. W. Yeo.
[illegible]			47, 000			New Mexico State engineer.
[illegible]	91, 760	5, 805	45, 580	51, 385	143, 145	New Mexico State engineer and chief engineer, Middle Rio Grande Conservancy District.

In a review of all available data on the history of irrigation development as pertaining particularly to the Middle Valley from Cochiti to San Marcial, C. R. Hedke, in a report of December 1924 to the New Mexico Interstate Compact Commission, presented an estimate of this development from 1600 to 1925. This estimate, as taken from the Hedke report, is shown in table 60. It will be noted that for 1880, 16 years before the Follett investigation, the deduction is made that there was a maximum of 124,800 acres "under development" from Cochiti to San Marcial. This is indicated to have declined to 50,000 acres in 1896 and to 45,000 acres in 1910.

TABLE 60.—[illegible] *Middle Rio Grande Valley, Cochiti to San Marcial, 1600–1925*

[illegible]	Number of ditches	Second-feet capacity	Acres under development	Acres [illegible]	[illegible]
[illegible]	[illegible]	537	25, 555		Indian development.
[illegible]	[illegible]	1, 415	73, 580		Indian with Spanish.
[illegible]	[illegible]	1, 808	100, 380		[illegible]
[illegible]	[illegible]	2, 099	123, 315		[illegible]
[illegible]	[illegible]	2, 145	124, 800		Transcontinental traffic and Civil War demand, [illegible]
[illegible]	[illegible]	1, 779	50, 000	74, 800	Due to short water supply, rising water table, railroad supply competition, and [illegible]
1910	[illegible]	2, 121	45, 220	79, 580	Further shortage and further rising water table.
1918	[illegible]	1, 957	47, 000	77, 800	War period.
[illegible]	60	1, 850	49, 000	84, 800	Estimated present condition.

As derived by C. R. Hedke and presented in report to New Mexico Interstate Compact Commission, December 1924.

The Elephant Butte-Fort Quitman Section

In the Follett account previously quoted there is only brief reference to the Elephant Butte-Fort Quitman section. In a report by R. G. Hosea submitted to the Rio Grande Survey Commission of New Mexico in 1928, the early history of this section is covered at some length as the result of considerable research by Hosea, and the following paragraphs are quoted or abstracted from his report:

The original Indian inhabitants of the El Paso Valley, the Mansos and Zumanas, were not an agricultural people; they had no permanent town and did not cultivate (or irrigate) their lands.

The first white settlement in the Lower Rio Grande Valley was founded December 8, 1659, by Fray Garcia de San Francisco y Zuniga—a mission dedicated to the Virgin of Guadalupe, and called El Passo. It was on the south side of the river about where the Mexican city of Juarez now stands. The first temporary buildings were replaced a little later by the church which is still standing in Juarez. The cornerstone was laid by Father Garcia in April 1662 and the building was dedicated January 15, 1668.

Two other missions were established prior to 1680 and a nucleus of Spanish settlers were living in the district at this time. In 1680 the Pueblo rebellion broke out in the country to the north and the Spanish colonists of New Mexico, driven out by the Indians, came to Paso del Norte under Otermin in September of 1680.

Otermin had with him 1,946 "persons of all kinds", including some 300 friendly Indians from Isleta, Sevilleta, Alamillo, Socorro, and Senecu, and more Indians came during the next year (1681). These Indians w re settled in three pueblos, Senecu, Isleta, and Socorro, near El Paso, in 1682, and the Spanish refugees were located at San Lorenzo at about the same time.

These settlements were consolidated at Guadalupe del Passo in 1684 for protection against the local Indians who had revolted. Food was very scarce, due to a drought and to Indian depredations, and the El Paso district came very near to being abandoned at this time.

This crisis passed, however, and in 1692–93 de Vargas reconquered most of the Pueblo Tribes of New Mexico, working north from El Paso as a base.

From 1700 to 1800 El Paso was the gateway to the northern [illegible] In 1760 the population was [illegible] in 1779 it was 4,934, not including Indians in either of the above figures.

Up to 1827 there were no houses or cultivated fields on the east side of the river, but in that year Juan Ponce de Leon acquired a grant of land of 200 to 500 acres and built an adobe house near the present location of the Mills Building in the [illegible]

After the Mexican War a number of new settlers came to the district and in 1859 the city of El Paso was surveyed by Gen. Anson Mills. At this time El Paso had a population of about 300 inhabitants, of whom 200 were Mexicans, while across the river a town of 13,000 people was flourishing.

Four railroads built into El Paso almost simultaneously, the Southern Pacific, the Santa Fe, and the Mexican Central in 1881, and the Texas Pacific in 1882, and in 1883 El Paso became the county seat of El Paso County, Tex.

The Spanish colonists of the El Paso district practiced irrigation from the time of their first occupation of the country, and from that date the irrigated area increased gradually until 1680, when the refugees from the Indian rebellion in New Mexico arrived. At this time several hundred Indians and Spaniards settled at Senecu, Ysleta, Socorro, and San Lorenzo, and a large increase in the irrigated area took place.

In 1851 there was a considerable area in cultivation on both sides of the river. Major Emory in his report to President Franklin Pierce states that the lands for 20 miles below El Paso (now Ciudad Juarez) were irrigated. This area was probably about 32,000 acres.

In the Mesilla Valley evidences of Peublo Indian villages are still visible on the west edge of the valley, about 8 miles above El Paso, Tex., and on the mesa west of the Oscar Snow ranch. Pottery has been found in still other localities.

Early Spanish settlements in the southern Rio Grande Valley were for the most part confined to the immediate vicinity of El Paso, on account of the hostility of the Apaches and other Indians.

The first application for the right to colonize the country with American settlers was made in 1822 by Dr. John Heath, for the "Bracito" tract. This was a tract 5 leagues square, with its center on an island in the Rio Grande about 30 miles above El Paso. This application was granted by the Emperor Iturbide on April 21, 1823, and John Heath with an American colony proceeded to his land grant by way of Mexico. Before the colony had time to get out of old Mexico, Iturbide was killed and the country was thrown into a state of revolution. The new government refused to acknowledge the grant to Heath, and the colonists were persecuted, robbed, and finally driven out of the country.

In 1805 Don Juan Antonio Garcia petitioned the governor of the province of New Mexico for a grant of land to extend from Bracito to the marsh or lake of Trujillo. Testimony given in a land grant hearing in 1849 showed that he lived on this land for [illegible] it and grazed stock, and was finally driven off by the Indians. Title to this tract was sold to Hugh [illegible] and patented by the United States Government.

At the time of Mexican independence (1821) the jurisdiction of which Paso del Norte was the center included the Mesilla [illegible] Dona Ana and south to San Lorenzo, Senecu, Ysleta and Socorro del sur. The entire population was about 8,000, nearly all of which was located in Paso del Norte and its immediate vicinity.

[illegible] 116 and led by Don Jose Costales in 1839, petitioned the governor of the State of Chihuahua for a grant of land on the east bank of the river known as "El Canon de Dona Ana." The grant was made and the settlers took possession in 1843. To each colonist was given a plat of land in a square 780½ varas in length, and to those who were not heads of families a parallelogram of equal length and one-half the breadth. The records show that there were 107 men, 59 women, 48 boys, and 47 girls in this colony.

On August 4, 1853, Mexico made a grant to the civil colony of Mesilla on the west side of the river near Mesilla, then in Mexico and later acquired by the United States under the Gadsden purchase. This colony consisted of about 300 families or a total of 1,500 people.

The Santo Tomas de Yturbide Colony was founded about 1848, the Refugio Colony about 1852, and the Jose Manuel Sanchez Baca grant about 1853.

Just prior to the Civil War the El Paso district ranked with the Santa Fe district in importance, and large areas of land were in cultivation in the Dona Ana Bend and the Mesilla Colony grants. In 1862 and 1865 disastrous floods in the Rio Grande changed the channel of the river and caused the abandonment of certain ditches and necessitated the construction of new ones. Such avulsions sometimes caused entire towns to be abandoned

The Mesilla ditch, which originally had its intake on the west side of the Rio Grande, watered lands about Picacho, Mesilla Bosque Seco, and old Santo Tomas. After the flood of 1865 most of the lands under this ditch were on the east side of the river and a new portion was built which connected the part remaining with the Las Cruces ditch at a point about halfway between Las Cruces and Dona Ana. Thereafter, both the Las Cruces and the Mesilla ditches used the same heading at El Tajo, near Hill, and the same ditch to El Partidor.

In 1870–80 the Mesilla Valley was very prosperous, but in the eighties a number of causes produced a slump in values and a contraction of the cultivated area. The railroad came in in 1881 and brought farm products from the Middle West. As the Indian menace decreased, the number of soldiers was decreased and the market furnished by the forts and Army posts became smaller.

The ever-shifting river bed made irrigation difficult and ditch maintenance expensive, and the summer water supply became very erratic and undependable. In 1903 the Acequia de las Amoles was destroyed, together with the village of the same name.

In the Rincon Valley the Pueblo Indian occupation is evidenced by abandoned villages, one of which is located on the east side of the Rio Grande above Derry and another at San Diego Mountain. The first permanent settlements were made at Santa Teresa and Colorado. The bold raids of the nomadic Apaches delayed the settlement of this valley.

In the Palomas Valley one old pueblo was located about a mile below Hot Springs, another about 2 miles above Las Palomas, and other evidences of early occupation have been seen.

The first settlement in this valley using water from the Rio Grande was at Las Palomitas above Las Palomas on the east side of the river. The Las Palomitas ditch was destroyed in 1887 and the town was later abandoned.

The town of Las Palomas, from which the valley derives its name, was one of the early settlements and receives water for irrigation from Palomas Creek.

In the area now occupied by the Elephant Butte Reservoir, the Pueblo Indians had villages along the edge of the valley as shown by the old pueblo at the edge of the mesa on the west side of the river and on the south side of Mulligan Gulch, and by another pueblo on the west side of the valley, about 1 mile above the present Elephant Butte Dam, and by other evidences of Pueblo Indian occupation.

The old Santa Fe-Chihuahua Trail traversed a portion of the upper part of the reservoir and passed down the west side of the Rio Grande to a point just below the lower end of Black Mesa. Opposite Paraje, the Rio Grande was crossed and the trail bore southeasterly and then southerly over the Jornada del Muerto. Paraje, during the occupation of Fort Craig, became in the seventies one of the largest towns between Albuquerque and Mesilla, as it was from Paraje that the difficult journey to the south across the Jornada del Muerto began.

The first Spanish settlements were probably established about the year 1820, after grant no. 33 to Pedro Armendaris was made, December 4, 1819, and after grant no. 34, also to Armendaris, was made, May 3, 1820. Settlements were made on these grants shortly after these dates.

In the early 1890's water shortages began to occur along Rio Grande in the Mesilla and El Paso Valleys, and people near Juarez, across the river from El Paso, complained to the Mexican Government. The matter was taken up through diplomatic channels, and in a claim for damages of $35,000,000 filed by Mexico against the United States it was alleged that the shortages were due to increasing diversions from the river by water users in Colorado and New Mexico. As a result, the International Boundary Commission was directed to make an investigation and report covering the whole upper Rio Grande situation. Under appointment from the commission this was done, as already noted by Follett. Follett's summary of his findings are quoted as follows:

1. The fact of a decrease in the flow of the river at El Paso exists, as claimed, and dates back to 1888 or 1889. Before those years the river went dry at intervals of about 10 years. Since 1888 it has been dry every year but two.

2. The use of water for irrigation has not materially increased in New Mexico since 1880, and hence is not the cause of this decreased flow.

3. The use of water in the San Luis Valley of Colorado has very largely increased since 1880, and at the present stage of development it takes from the river, in excess of what was taken in 1880, an amount of water equivalent to a flow of 1,000 second-feet, running for 100 days; at least this amount is taken and possibly more.

4. It is impossible to state specifically how much water was in the river prior to this increased use of water and since, as the records do not antedate this increased use, and as the flow since the records began varies within very wide limits.

5. This flow of 1,000 second-feet, if allowed to remain in the river, would do much toward preventing a dry river at El Paso. Hence—

6. The Mexican and American citizens of the El Paso Valley have suffered in common with their neighbors of the Mesilla Valley and those still farther up the river by this Colorado increased use of water. The suffering has been greater in the El Paso Valley than elsewhere.

7. All of the summer flow of the steams in the San Luis Valley, except their floodwaters, are now appropriated, and therefore the use of water therein for direct irrigation is not likely to materially increase in the future.

An immediate result was the promulgation of the "embargo" by the Department of the Interior. The nature and operation of this embargo have been previously noted in this report.

Mexico continued to press its claims and through the efforts of the Department of State, the Department of the Interior undertook an investigation of the river and a study looking to some means of providing water to satisfy the Mexican demands. The investigation revealed the feasibility of constructing Elephant Butte Reservoir for the storage and regulation of Rio Grande flow passing San Marcial. It was reported that reasonable demands for water upon the part of Mexico could be satisfied, and that, with inflow rights properly protected, the reservoir could also furnish water for an area in New Mexico and Texas estimated at 155,000 acres. This was designated as the Rio Grande Project of the Reclamation Service, and the Leasburg unit was approved for construction by the Secretary of the Interior December 2, 1905. By an act of February 25, 1905, Congress authorized construction of the storage dam, and in March, 1907, appropriated $1,000,000 toward the construction as representing that part of the total cost involved in the provision of water for Mexico. A treaty between the United States and Mexico was signed May 21, 1906, and proclaimed by the President January 16, 1907. Under the terms of this treaty the United States guaranteed to Mexico, in return for relinquishment of all claims for damages, the annual delivery in perpetuity of 60,000 acre-feet of water in the bed of Rio Grande at the head of Acequia Madre, the Mexican canal opposite El Paso. The monthly distribution of this amount is specified in the treaty and there is a clause which provides that, "In case, however, of extraordinary drought or serious accident to the irrigation system in the United States, the amount delivered to the Mexican canal shall be diminished in the same proportion as the water delivered to lands under said irrigation system in the United States."

Notices of intention to appropriate Rio Grande waters for the Elephant Butte Reservoir and the Rio Grande Project were filed in the office of the territorial engineer of New Mexico by the Reclamation Service in 1906 and 1908. The notice of January 23, 1906, names 730,000 acre-feet and that of April 8, 1908, "all the unappropriated water of the Rio Grande and its tributaries." Both specify a storage reservoir of 2 million acre-feet capacity. The Secretary of the Interior approved construction of the Elephant Butte Dam on May 23, 1910, and the dam, providing a reservoir of 2,639,000 acre-feet capacity, together with the diversion dams and canal systems of the Rio Grande Project, was completed in 1916. About 1918 the necessity for drainage on the Project became apparent and by 1925 a complete system of open drains was constructed. Land owners on the Rio Grande Project represented by the Elephant Butte Irrigation District in New Mexico and the El Paso County Water Improvement District No. 1 in Texas have contracted with the Government for full

repayment of all construction costs of the Project, except for the million dollars appropriated by the Congress to cover the cost of supplying water to Mexico under the terms of the treaty of 1906. The total construction cost of the Project to date is about 15 million dollars.

In 1924 the Hudspeth County Conservation and Reclamation District No. 1, comprising 20,000 acres of El Paso Valley in Texas below the Rio Grande Project, was organized to consolidate into one canal system several ditches which had been built about 1915, and which were diverting water from Rio Grande at various points between the Rio Grande Project boundary and Guayuco Arroyo which now marks the lower or eastern terminus of the Hudspeth district canal system. Under a Warren Act contract between the Hudspeth district and the United States, the district has, since 1925, been making a direct diversion of drainage and waste waters of the Rio Grande Project.

Acreage irrigated.—It is stated in the Follett report that the combined capacity of all canals in El Paso Valley in the late sixties, as determined from evidences found in 1896, was 300 second-feet on the Mexican side of Rio Grande and 250 second-feet on the American side, and that 40,000 acres had been irrigated. If the areas irrigated were in proportion to the capacity of the ditches on the two sides, the area irrigated in Mexico was about 22,000 acres and that on the American side 18,000 acres. For the Mesilla and Rincon Valleys, Follett in 1896 reported 29 ditches with a total capacity of 974 second-feet, irrigating 36,950 acres.

In a 1928 report by Herbert W. Yeo, then State Engineer of New Mexico, a deduction of the irrigated acreages in the New Mexico and Texas areas of the Upper Rio Grande Basin is made for 1907 and 1928. The following paragraphs quote this report with respect to the derivation of the data for the Elephant Butte-Fort Quitman section.

For the area south of San Marcial irrigated from the Rio Grande, maps and notes filed in the United States Bureau of Reclamation at El Paso were freely consulted. The area includes the land within the present Elephant Butte Reservoir, the Palomas Valley, Rincon Valley, Mesilla Valley, and El Paso Valley.

For the area irrigated within Elephant Butte Reservoir the topographic maps of the reservoir were consulted. The surveys for the reservoir were made in 1903–4 and 1907–8.

Data concerning the area irrigated in the Palomas Valley were obtained from old residents of the valley (and are subject to their error) and from topographic maps made in 1903.

Information as to irrigated lands in the Rincon Valley is obtained from topographic maps made in 1912 by the United States Reclamation Service. At the time these maps were made the Reclamation Service had not constructed any irrigation works in Rincon Valley and the area irrigated was substantially the same as in 1907.

A survey of the irrigable lands in Mesilla Valley was made in 1903–4 by the United States Reclamation Service, and the maps show the area irrigated at that time. The acreage shown as irrigated on these maps was practically the same in 1907. In addition to the above the United States Reclamation Service made a detailed survey in 1907 of the lands irrigated under the Doña Ana, Las Cruces, and Mesilla ditches.

The area irrigated in the El Paso Valley in 1908, as determined by Homer J. Gault, is shown on a map of the irrigable lands of the Rio Grande project in Texas which was made by the United States Reclamation Service.

Information concerning the irrigated acreage on the tributary streams south and west of San Marcial was gathered in 1928. Facts relative to the area cultivated in 1907 were given by residents on the various streams and from records on file in the Sierra County courthouse in Hillsboro. This information was later checked in the field and is believed to be fairly correct. The area irrigated on the various tributaries is limited by the water supply and the cultivated acreage has not varied appreciably for many years.

Based upon these data, the Yeo report gives the following figures for the irrigated acreage in the Elephant Butte-Fort Quitman section in 1907:

Valley subdivision:	Irrigated acres
El Paso Valley (American side)	8, 537
Mesilla Valley	26, 229
Rincon Valley	4, 370
Palomas Valley	150
Elephant Butte Reservoir area	2, 080
Tributaries below San Marcial	4, 475
Total	45, 841

For his 1928 summary Yeo used the 1927 data for the Rio Grande Project and other valley areas below Elephant Butte Dam, as the 1928 data were not yet available. Substitution of the latter as obtained from the Rio Grande Project history for 1928 and use of Yeo's figures for tributaries below San Marcial give the following figures for the irrigated acreage in the Elephant Butte-Fort Quitman section in 1928:

Valley subdivision:	Acres irrigated in 1928
Fort Hancock area (Hudspeth district and lower)	15, 000
El Paso Valley—in Mexico (estimated)	35, 000
El Paso Valley—Rio Grande Project	55, 460
Mesilla Valley—Rio Grande Project	76, 057
Rincon Valley—Rio Grande Project	[illegible]
Palomas Valley	390
Tributaries below San Marcial	4, 530
Total	[illegible]

To be comparable with the 1907 total, that for 1928 should exclude the estimate of Mexican acreage.

In 1914 the Bureau of Reclamation made a complete survey of the cropped and irrigated acreages in what is now the area included in the Rio Grande Project. The data reported by this survey, those of Follett and Yeo as previously outlined, and those available from Rio Grande Project records beginning with 1920 are brought together in table 61.

TABLE 61.—*Acreages irrigated in Elephant Butte-Fort Quitman section—Upper Rio Grande Basin*

Year	Tributary areas	[illegible] Butte Reservoir area[1]	[illegible]	[illegible] ([illegible]): [illegible] Valley	[illegible] Valley	[illegible] Valley	Total	Lower El Paso Valley[2]	Mexican area[3]	Total[4]
[illegible]				[illegible]	27,100	[5] 18,000	54,950	—	[illegible]	
[illegible]	[illegible]	2,080	[illegible]	[illegible]	26,229	8,537	39,136			
[illegible]				[illegible]	45,356	17,281	69,598			
[illegible]				[illegible]	48,327	27,283	[illegible]	1,011	[illegible]	[illegible]
[illegible]				6,570	51,407	26,430	84,407	1,120	[illegible]	[illegible]
[illegible]			18	5,880	48,620	29,720	84,220	[illegible]	[illegible]	[illegible]
[illegible]			[illegible]	6,201	53,812	32,359	92,372	6,587	20,000	[illegible]
[illegible]			[illegible]	6,357	[illegible]	47,669	[illegible]	[illegible]	20,000	[illegible]
[illegible]			267	9,344	67,356	54,211	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]			210	11,530	76,244	54,749	142,523	[illegible]	[illegible]	[illegible]
[illegible]			[illegible]	10,701	73,314	53,538	137,553	[illegible]	35,000	185,373
[illegible]	4,530		390	11,807	76,057	55,460	143,324	13,600	35,000	196,844
[illegible]			[illegible]	12,480	76,772	[illegible]	144,197	13,500	35,000	[illegible]
[illegible]			358	12,702	76,373	[illegible]	144,607	[illegible]	[illegible]	[illegible]
[illegible]			389	13,069	76,722	54,499	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]			[illegible]	12,463	[illegible]	48,277	137,449	[illegible]	30,000	[illegible]
1933			1,074	12,283	77,061	49,862	139,206	12,788	30,000	183,068
[illegible]			1,118	12,776	68,605	47,711	129,092	13,055	30,000	[illegible]
[illegible]	....		825	11,834	62,175	46,066	120,075	13,533	30,000	[illegible]

[1] [illegible]
[2] [illegible]
[3] [illegible]
[4] Figures do not include tributary areas except for 1928.
[5] [illegible]

Present Development

Present irrigation development in the Upper Rio Grande Basin may be largely expressed in terms of the magnitude of present irrigated areas. However, where the water supply is not fully regulated by storage, the acreage irrigated from year to year may vary considerably in accordance with the available supply, and due consideration must be given to this fact in the use of data covering the irrigated areas of any one year as a measure of the irrigation development. As a part of the Rio Grande joint investigation, a complete survey and classification of the irrigated lands and vegetative cover on all water consuming areas throughout the Upper Rio Grande Basin in 1936 was made by the Bureau of Agricultural Engineering. The results of the survey are fully reported in Part III of this report, and summarized in table 71 of the following section on water uses and requirements. In the remainder of this section, data of this survey, together with data derived from reports of past investigations by Colorado, New Mexico, and Federal agencies, are drawn upon to present the essential facts of present irrigation development. Data given as "acreage irrigated" represents the area actually irrigated in 1936 after a 3-percent deduction has been made from the total area as mapped to allow for roads, lanes, canals, farmsteads, the strips of uncropped land along fences and the like. These deductions were restored in the tabulations as water areas in the case of canals and drains, grass areas in the case of marginal strips along roads and fences, and so on. Data under the head of "other water-consuming acreage" include areas of native vegetation, water surfaces of rivers, canals and drains, bare lands, lands temporarily out of cropping, and cities, towns, and villages. The "total" acreage given is the area mapped and represents the sum of the areas irrigated and the other water-consuming areas.

The San Luis Section

Irrigated and other water-consuming areas in the San Luis section as shown by the 1936 survey totaled 1,446,652 acreas. The segregation to the closed basin, southwest area, and southeast area is shown in table 62. In the southwest area are included the mountain valleys on Rio Grande above Del Norte and on the Conejos above Mogote.

TABLE 62.—*Irrigated and other water-consuming areas, San Luis section, 1936*

Subdivision	Acreage irrigated	Other water-consuming acreage	Total
Southwest area	270,350	212,181	482,531
Southeast area	51,971	178,725	230,696
Closed basin	277,922	455,503	733,425
Total, San Luis section	600,243	846,409	1,446,652

In the mountain valleys above Del Norte the irrigated areas as found in 1936 comprise 11,901 acres on the main Rio Grande, 950 acres on the South Fork, and 4,984 acres on Pinos Creek. Just below Del Norte there are 2,172 acres irrigated on San Francisco Creek. Between the point of diversion of the Del Norte Irrigation District canal, about 12 miles above Del Norte, and Alamosa are located the headings of practically all of the larger canals which divert from Rio Grande. The name and location of these canals are shown on the map, plate 11, Part III of this report. Of the canals diverting to the north, the Rio Grande, Farmers Union, McDonald, Prairie, San Luis Valley, and Costilla carry

water into the closed basin. The acreage irrigated in 1936 in the area thus served from Rio Grande amounted to 172,944. The remaining acreage irrigated from Rio Grande in 1936, in the southwest area, totaled 141,947. This covers the narrow strip between the river and the southern boundary of the closed basin, and the area extending south and west from the river to Alamosa and La Jara Creeks. It will be observed that over half of the San Luis Valley acreage irrigated from Rio Grande is in the closed basin, from which, except for the outlet of the Rio Grande drain, there is no return flow to the river.

Irrigation systems in the area served from Rio Grande are organized and operated in three ways—as irrigation districts, mutual associations, or private holdings. Practically all the systems of any magnitude come under the first two forms of organization. Irrigation districts included are the San Luis Valley, Mosca, and Del Norte. The first two are in the closed basin and the Del Norte district is on bench lands north of Rio Grande between Del Norte and Monte Vista. The San Luis Valley Irrigation District, embracing about 67,000 acres, owns the Rio Grande Reservoir and the Farmers Union canal system. It irrigated 46,267 acres in 1936. The district has constructed and operates a drainage system as well as its irrigation system. The Mosca Irrigation District includes about 32,000 acres in three major units scattered throughout a gross area of about 75,000 acres. It owns and operates the Beaver Park Reservoir, capacity 4,400 acre-feet, on the south fork of Rio Grande, and the system of the San Luis Valley canal. Water can be diverted to the central and southern laterals of this system from the outlet drain of the Rio Grande Drainage District. There were 6,758 acres irrigated in 1936. It appears that much of the land in this district is in need of drainage. The Del Norte Irrigation District, comprising 10,000 acres, controls the Continental Reservoir, capacity 26,700 acre-feet, and owns and operates the Del Norte canal system. In 1936 some 3,000 acres were irrigated within its exterior boundaries.

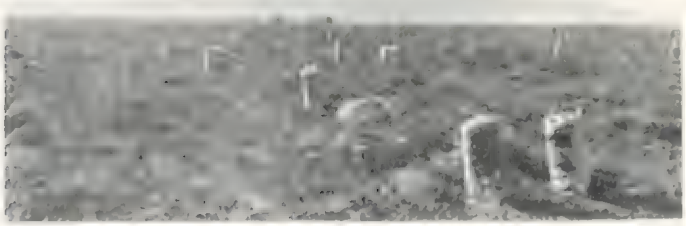


Table 63 lists all of the active irrigation districts in San Luis Valley and for each gives the gross acreage, acreage irrigated in 1936, source of water supply, and storage capacity controlled.

TABLE 63.—*Active irrigation districts in San Luis Valley, Colo.*

[illegible]	[illegible]	[illegible]	[illegible]	Storage capacity controlled	
				[illegible]	[illegible]
[illegible]	10,000	[illegible]	[illegible] tributaries	Continental...	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	Beaver Park..	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	Terrace.......	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The Rio Grande canal was built by the Traveler's Insurance Co. and operated by it until 1930, when the Rio Grande Canal Water Users' Association purchased control of the system, which includes the Santa Maria Reservoir, capacity 42,000 acre-feet. Of a total of 142,196 acres mapped as under the canal, 111,844 acres were irrigated in 1936. The Monte Vista canal system, including about 30 miles of main canal, heads a short distance above Monte Vista and extends southeasterly beyond Alamosa Creek. This canal was likewise built by the Traveler's Insurance Co. and has now been purchased by the water users under it, who also share in Santa Maria Reservoir. More than 24,000 acres were irrigated in 1936. The Empire canal heads below Monte Vista and parallels the Monte Vista canal at a distance of 3 to 6 miles to the east of it, extending to La Jara Creek. This canal system is controlled by a water users' association. In 1936, 20,794 acres were irrigated. Other canals diverting from Rio Grande are owned privately or are controlled by groups of water users; they irrigate smaller areas than those of the larger canal systems and districts that have been enumerated.

In the southwest area south of the lands irrigated from Rio Grande are those served by Alamosa and La Jara Creeks and Conejos, Los Pinos, and San Antonio Rivers. In addition, there are small areas under Raton, Rock, Spring, and Cat Creeks between Rio Grande and Alamosa Creek, and under Hot Creek between the latter and La Jara Creek. Spring Creek joins Rock Creek about 5 miles west of the Gunbarrel Road and the channel below is used in the collection and distribution of drainage and irrigation water throughout its length. Drains of the McLean, Parma, Bowen, Waverly, and Carmel drainage districts empty into it above its junction with Alamosa Creek about 3 miles above the junction of the latter with Rio Grande.

Water is distributed from Alamosa Creek by the canals of the Terrace Irrigation District, and a number

of smaller ditches. The Terrace Irrigation District, comprising about 14,000 acres, owns the Terrace Reservoir on Alamosa Creek, capacity 17,700 acre-feet, and operates the Terrace and Alamosa Canal systems. Some 6,455 acres were irrigated within the exterior boundaries of this district in 1936. Water from La Jara Creek is distributed in small canals diverting from both sides. La Jara Reservoir, capacity 14,000 acre-feet, on La Jara Creek, is owned and operated by a group of water users.

There is a small amount of irrigation in the mountain valleys of Conejos River. It totaled 1,151 acres in 1936. Below, on the valley floor, irrigation from the Conejos and San Antonio Rivers extends east to the San Luis Hills and north to join the area irrigated from La Jara Creek and Rio Grande. There are no irrigation districts or large canal associations in this area. The ditches, nearly all small, are numerous and are the result of efforts by individuals or small community groups. There are no reservoirs on the Conejos, Los Pinos or San Antonio Rivers. Cove Lake Reservoir, capacity 9,700 acre-feet, is in the southeast corner of the southwest area in Poncha Valley. Water is diverted to the reservoir by a canal from San Antonio River. This was originally a project of the Taos Valley Irrigation Co., now out of existence. Some 680 acres were irrigated from the reservoir in 1936.

According to the 1936 survey, the acreage irrigated under Alamosa and La Jara Creeks and the minor streams to the north was 49,018, of which a part received some water also from Monte Vista Canal. Under Conejos, Los Pinos and San Antonio Rivers in Colorado, 82,389 acres were irrigated, and the San Antonio and Los Pinos irrigated 541 acres in New Mexico. As shown by the 1936 data, there were 36 ditches diverting from Alamosa Creek, 28 from La Jara Creek, and 121 from Conejos River and its tributaries.

In the southeast area, the irrigation development is that dependent on the Trinchera stream system in the north and Culebra Creek and Costilla River in the south. Practically the entire area is included in the original Sangre de Cristo Grant, later divided into the Trinchera and Costilla estates. Below several hay ranches, Trinchera Creek and its tributaries are entirely controlled by Mountain Home and Smith Reservoirs of 20,100 and 6,200 acre-feet capacity respectively, owned and operated by Trinchera Irrigation District. The latter, comprising about 35,000 acres, succeeded the Trinchera Estates Development Co. in 1910. The acreages irrigated in 1936 were 11,447 within the district boundaries, 2,669 from the stream system above the district, and 4,539 south and west of the district. In addition to the condition of a surplus of arable land for which there is no water supply, high transportation and other losses in the use of the available supplies combine to leave practically no residual flow to Rio Grande from Trinchera drainage.

The waters of Culebra Creek and Costilla River are diverted by individual and community ditches along the upper valleys of these streams and through the irrigation system of the Costilla Estates Development Co. to the bench lands lying between the two streams at an elevation of from 100 to 200 feet above Rio Grande. Sanchez Reservoir of the Costilla Estates Development Co. is on Ventero Creek, tributary to Culebra. A canal conducts water from Culebra, Vallejos, and San Francisco Creeks via Torcido Creek to the reservoir. Although the capacity is 104,000 acre-feet, the water stored has seldom, if ever, approached this amount. Eastdale Nos. 1 and 2 Reservoirs, with capacities of 3,500 and 3,000 acre-feet respectively, and also owned by Costilla Estates Co., are constructed off the stream channels and receive water through canals diverting from Culebra Creek and Costilla River. Their purpose is to provide regulatory storage for the lands on the western side of the Costilla Estates project. The project extends into New Mexico, and the Costilla Reservoir, capacity 20,700 acre-feet, on Costilla River in New Mexico, is a part of it. However, most of the lands irrigated from Costilla River are in Colorado. The present system of the Costilla Estates Co. makes possible the use of water from both Culebra Creek and Costilla River on the area between the two streams. The acreage thus irrigated in 1936 was 32,455 in Colorado and 188 in New Mexico. Outside of the Costilla Estates project, 2,696 acres were irrigated from Costilla in New Mexico. The New Mexico acreage is not included as a part of the southeast area of the San Luis section. As in the case of the Trinchera area, the irrigable land under Culebra Creek and Costilla River is greatly in excess of the available water supply, so that little of it reaches Rio Grande.

Present development in the closed basin with respect to areas irrigated by diversions from Rio Grande, chiefly through the Rio Grande, Farmers Union, Prairie,

FIGURE 24.—Conejos River Valley. The lower reservoir site.

San Luis Valley, and Costilla canals, has been previously described. Other irrigated areas in the closed basin are those served by La Garita and Carnero Creeks on the west, Saguache Creek in the northwest, Kerber and San Luis Creeks on the north and numerous small creeks from Cotton to Zapato on the east. The area under La Garita and Carnero Creeks lies on the extreme western border of the valley. It is served by small community or private ditches. Practically the entire flow of the streams is applied to the land, but as the soils are open and porous, much of the water applied probably moves underground to lower lands under the Rio Grande canal to the east, or enters the artesian aquifer underlying the valley. In the lower areas waters from La Garita and Carnero Creeks are commingled with those brought from Rio Grande, so that it is difficult to segregate the acreage irrigated from any one source. Approximately 2,057 acres were irrigated from La Garita and 1,052 from Carnero Creek in 1936.

In the Saguache Creek area there were 12,086 acres irrigated in 1936 in the mountain valleys of Saguache Creek above Gunbarrel Road, and 29,576 acres in the vicinity of and below the town of Saguache. A terminal wasteway of the Rio Grande canal empties into Saguache Creek channel so that the acreage irrigated below this point may be served from two sources. By far the greater portion of the irrigated acreage in the Saguache area is wild hay land.

The acreage irrigated from Kerber and San Luis Creeks and the small creeks draining the short western slope of the Sangre de Cristo Range in the closed basin is practically all pasture or wild hay land. In 1936 the total acreage irrigated in this area was 46,453 of which 42,859 acres were pasture and wild hay. The low proportion of cultivated crops is an indication of the character of the water supply, as natural grass for hay or pasturage is grown more or less generally throughout the valley where the water supply is deficient, erratic, or unreliable, while cultivated crops are grown where the supply is, in the main, sufficient and certain. Very few of the east side streams are perennial down to or even near to the agricultural areas, and irrigation is largely confined to flooding hay land and to raising the ground-water level. The streams as far south as Deadman Creek would naturally be tributary to San Luis Creek, but only during periods of exceptionally high run-off do their surface waters reach so far, as they are spread over wild hay or largely absorbed by the loose gravelly soil which skirts the base of the mountains in which the creeks rise. From Deadman Creek to the southern boundary of the closed basin, the streams are practically all ephemeral in their lower reaches near the sump area. These streams debouch from rocky canyons upon alluvial fans of gravel and coarse soil resulting in a large and rapid percolation of their flow to ground water. Any surface flow that remains is diverted to wild hay or meadow lands east of the Sump.

The Middle Section

The irrigated and other water-consuming areas in the Middle section as determined by the 1936 survey are shown by table 64.

TABLE 64.—*Irrigated and other water-consuming areas, middle* [illegible]

[illegible]	[illegible]	[illegible]	Total
[illegible]	86,813	62,142	[illegible]
[illegible]	[illegible]	6,987	12,878
[illegible]	[illegible]	[illegible]	205,076
Total	[illegible]	[illegible]	[illegible]

[illegible]

In the following paragraphs, the tributary areas are considered in downstream order from the Colorado-New Mexico State line.

On Costilla River the lands irrigated in New Mexico fall in three groups—those in the upper valley, those adjacent to the town of Costilla, and those under the Costilla Estates Development Co. The 1936 irrigated acreages in these groups were, respectively, 1,063, 1,633, and 188. As noted under development in the southeast area of San Luis section, Costilla Estates Development Co. owns Costilla Reservoir on Costilla River in New Mexico, but most of the lands irrigated under this development are in Colorado. The irrigation system of the company was constructed to serve about 15,000 acres in New Mexico.

East of Rio Grande, reaching from the Colorado line to Rio Colorado, there is an extensive smooth plain called Cerro Mesa. In the south-central portion of this mesa the Cerro community ditch diverts the waters of Latir Creek and smaller creeks to the south for irrigation near the settlement of Cerro. Some 2,402 acres were thus irrigated in 1936. At the southern end of Cerro Mesa the waters of Cabresto Creek and Rio Colorado are used near the settlements of Red River and Questa. Two community ditches are maintained on Cabresto Creek in conjunction with a small reservoir, Cabresto Lake. The acreage irrigated in 1936 from Rio Colorado near Questa and in the canyon above amounted to 2,846.

On San Cristobal Creek there is a small irrigated valley and on Rio Hondo, in the vicinity of Arroyo Hondo, a substantial acreage is irrigated from both Rio Hondo and Arroyo Seco. In 1936 the latter totaled 3,676 acres, and that on San Cristobal Creek was 576 acres. There is a ditch which diverts Arroyo Seco water to Taos Mesa and the acreage thus irrigated is included in that given below for Taos Mesa.

Taos Mesa extends for about 20 miles from Rio Hondo Canyon on the north to the Picuris Mountains on the south and lies between the Rio Grande Canyon on the west and the foot of the Sangre de Cristo Range on the east. Lands on this mesa are irrigated from Arroyo Seco, Rio Lucero, Rio Pueblo de Taos, Rio Fernando de Taos, and Rio Ranchos de Taos. The acreage shown to be thus irrigated in 1936 was 11,191. The arable lands of this mesa appear to far exceed the available water supply so that practically all of the latter is utilized. There is, however, no storage to permit utilization of flood flows in excess of diversion capacities. The Taos Indian Pueblo is located just north of the town of Taos. Its agricultural lands are under ditch systems which divert from Rio Lucero and Rio Pueblo.

On the Aguaje de la Petaca, a small stream joining Rio Grande from the west a few miles below the Rio Taos junction, there is an irrigation development originally organized by the Settlers Ditch & Reservoir Co. to irrigate about 5,000 acres. It is now organized as the Carson Irrigation District, comprising 9,400 acres. An earth and rock fill dam on Aguaje de la Petaca was completed in July 1936, forming a reservoir of 7,400 acre-feet capacity. This development is planned to serve about 4,800 acres of the total district area. No land was irrigated in 1936.

South of the Picuris Mountains is the drainage of Embudo Creek, joining Rio Grande from the east a short distance above Embudo. Along this stream and its tributaries, Rio Pueblo, Las Trampas, and Ojo Sarco, there are many narrow irrigated valleys shown by the 1936 survey to have included irrigated areas totaling 6,504 acres. The Picuris Indian Pueblo is located on Rio Pueblo.

In the mountain valleys of Rio Truchas, an eastern tributary of Rio Grande at the upper end of Espanola Valley, there were 1,449 acres irrigated in 1936.

Irrigation development on Rio Chama, a western tributary which drains an area of 3,200 square miles and joins Rio Grande just above the town of Espanola, comprises valley lands on the main stream, chiefly from the town of Chama to the vicinity of Park View and between Abiquiu and Rio Grande, and lands in the mountain valleys of numerous tributaries. Irrigation in the Rio Chama drainage is accomplished almost entirely by small individual or community ditches. The irrigated acreages as determined by the 1936 survey are given in table 65.

Joining Rio Grande just below the town of Espanola are Rio Santa Cruz from the east and Santa Clara Creek from the west. The Santa Cruz Irrigation District is situated in the Rio Santa Cruz Valley. In 1929 it completed a dam on Rio Santa Cruz about 1 mile above Chimayo forming Santa Cruz Reservoir of 4,600 acre-feet capacity. This development supplements irrigation by direct diversion along Rio Santa Cruz which has been carried on from a very early date. The acreage irrigated in 1936 on Rio Santa Cruz above the Santa Clara Pueblo Grant was 3,628. The water of Santa Clara Creek is used by the Santa Clara Indian Pueblo, which also diverts from Rio Grande and gets some water from Rio Santa Cruz as well.

TABLE 65.—*Irrigated areas in Rio Chama drainage, 1936*

Subdivision	
Chama and tributaries above El Vado Reservoir	7,921
Main stream and tributaries, except El Rito, El Vado to Abiquiu	5,725
El Rito	3,857
Main stream and tributaries, except Ojo Caliente, Abiquiu to mouth	[illegible]
Ojo Caliente and its tributaries, Tusas and Vallecitos	8,715
Total	28,613

Pojoaque Creek enters Rio Grande from the east at the San Ildefonso Indian Pueblo at the lower end of Espanola Valley and just above the Otowi Bridge gaging station on Rio Grande. It has two principal tributaries, Nambe and Tesuque Creeks. The Nambe and Tesuque Indian Pueblos are located on Nambe and Tesuque Creeks, respectively, and divert these streams for irrigation. San Ildefonso Pueblo irrigates from Pojoaque Creek. The 1936 acreage irrigated on Pojoaque Creek and its tributaries was 3,174. This does not include an area along Rio Grande but irrigated from Pojoaque Creek.

Santa Fe Creek joins Rio Grande near the Indian Pueblo of Cochiti at the upper end of Santo Domingo Valley. The city of Santa Fe is situated on this creek about 25 miles above its mouth just at the foot of the Sangre de Cristo Range at an elevation of 7,000 feet. The water of Santa Fe Creek is practically all used for municipal purposes in Santa Fe and some irrigation near the city. The New Mexico Power Co. owns three small reservoirs on the creek above Santa Fe which are operated for the municipal supply. Irrigation from Santa Fe Creek and tributaries in 1936 covered 1,496 acres.

There are a few small irrigated acreages along Galisteo Creek which is practically the last stream, except for arroyos of erratic flow, to enter Rio Grande from the east above Fort Quitman. In fact, the flow of Galisteo Creek itself is by no means perennial and the water reaching Rio Grande at its junction near the Indian pueblo of Santo Domingo is largely that brought down as the result of sudden storms in the summer. The total area irrigated along Galisteo Creek in 1936 amounted only to 39 acres.

[illegible] N. Mex.

Jemez Creek joins Rio Grande from the west just below the Angostura diversion of the Middle Rio Grande Conservancy District, or about 7 miles above Bernalillo. It drains the south slope of the high Jemez Mountains and has a drainage area of 1,000 square miles. However, most of the flow is either used in irrigation in upper valleys along the stream or sinks into the ground in a barren sandy stretch of more than 10 miles. Little water, therefore, other than that from spring run-off and summer storms, reaches Rio Grande. There are three Indian pueblos along Jemez Creek. In downstream order they are Jemez, Zia, and Santa Ana. The first two use Jemez Creek waters for irrigation but the irrigated lands of the Santa Ana Indians are 10 miles below the pueblo in the Rio Grande Valley and are served from the main river. There are other irrigated lands above Jemez pueblo and below it in the vicinity of San Ysidro. The 1936 survey showed 2,496 acres irrigated in the valleys of the Jemez Creek drainage.

There are no tributaries upon which there is irrigation between Jemez Creek and Rio Puerco. The latter, which joins Rio Grande from the west a short distance above San Acacia, or about 65 miles below Albuquerque, has a drainage area of 5,000 square miles. This area is, however, relatively low and there is little perennial flow from mountain snow fields to its upper valleys and practically no flow to Rio Grande other than that resulting from intermittent and torrential storms. There are two principal irrigation areas in the Puerco Basin, the Cuba and Bluewater. The upper Rio Puerco and its tributaries, La Jara Creek, Salado Creek, San Jose Arroyo, Rito de los Pinos, Rito de los Utes, Rito Leche, and Nacimiento Creek, comprise the so-called Cuba Valley. In 1936 there were 4,600 acres irrigated in the various small valleys of the area. Since the streams are not perennial, water for irrigation may be available for only a few weeks in spring or following intermittent summer storms. There is, however, a fairly good annual precipitation, so that some crops can be grown with the irrigation supply indicated.

On Bluewater Creek, a southwestern tributary of Rio Puerco, present irrigation development is under the Bluewater-Toltec Irrigation District. The District owns and operates the Bluewater Reservoir, capacity 57,500 acre-feet, on Bluewater Creek, and in 1936 the acreage irrigated on the project was 3,227.

Below the junction of Bluewater Creek with Rio San Jose, which is tributary to Rio Puerco, there are two Indian pueblos, Laguna and Acoma, which in 1936 diverted water from Rio San Jose for the irrigation of 5,072 acres. On tributary streams below Grants 2,073 acres were irrigated.

Including all other small irrigated areas with those of the Cuba and Bluewater districts, the total acreage irrigated in the Rio Puerco Basin in 1936 was 14,972.

Irrigation development in the main valleys along Rio Grande from Embudo to San Marcial is, for purposes of this description, divided to that of Espanola Valley, that under the Middle Rio Grande Conservancy District from Cochiti to the southern third of Socorro Valley, and that from the lower end of the Middle Rio Grande Conservancy District to San Marcial.

In the Espanola Valley from Embudo to White Rock Canyon there are about eight ditches which divert water for irrigation from Rio Grande. Although these are old and probably follow much the same course and irrigate the same lands as in the early days of the Spanish occupation, their headings in the river are still more or less temporary rock and brush wing dams which must be replaced with the passage of each flood or reoccurrence of high water. In a few instances, several small ditches have been combined into community ditches such as the Alcalde. The management of the ditches continues much as in early times; each landowner under a ditch contributes labor for its maintenance and a majordomo distributes the water. Included in the irrigation development of Espanola Valley is that of three Indian pueblos, San Juan, Santa Clara, and San Ildefonso. As previously noted, Santa Clara pueblo obtains water from Rio Santa Cruz and Santa Clara Creek and San Ildefonso pueblo from Pojoaque Creek, thus supplementing their Rio Grande supplies. The total acreage irrigated in Espanola Valley in 1936 was 5,700. Some of this was irrigated from tributary sources, rather than from the main river. There are two small areas in the Rio Grande Canyon above Embudo where a small amount of water is diverted for irrigation. These are Rinconada and Cieneguilla Valleys, in which 191 acres were irrigated in 1936.

In the area of the Middle Rio Grande Conservancy District there were, at the time of the formation of the district, nearly 70 old ditches diverting water from Rio Grande by means of temporary headings. This net-

work of ditches was largely rebuilt by the district and incorporated into a system which accomplishes the river diversion at six headings and embraces approximately 1,000 miles of canals. The district is divided into four irrigation divisions which are, in downstream order, Cochiti, Albuquerque, Belen, and Socorro. The diversion dams, headings, and main canals, as shown on the maps, plates 13 to 16, inclusive, are Cochiti Dam diverting to Cochiti and Sili main canals on the east and west sides of the river, respectively; Angostura Dam, diverting to Albuquerque main canal, east side; Atrisco heading opposite Albuquerque, diverting to Arenal main canal, west side; Isleta Dam diverting to Peralta and Belen High Line main canals, east and west sides, respectively; San Juan heading diverting to San Juan main canal, east side; and San Acacia Dam diverting to Socorro main canal, west side.

Most of the lands in the Middle Valley are privately owned. Title came originally through land grants made by the kings of Spain. However, in accordance with the Spanish custom of inheritance under which ownerships are subdivided and resubdivided with succeding generations, the original grants have been reduced to an extremely large number of very small, irregularly shaped tracts. This is strikingly shown on the maps which display the vegetative cover classifications in the Middle Valley. The management of the Middle Rio Grande Conservancy District is charged with furnishing service to approximately 30,000 properties.

The drainage system constructed by the district includes 334 miles of drains, of which 181 miles are riverside drains and 153 miles interior drains. El Vado Reservoir, 198,000 acre-feet capacity, on Rio Chama 60 miles above its confluence with Rio Grande, is owned by the Middle Rio Grande Conservancy District and operated as a supplemental source of supply for the lands of the district.

As stated in the Burkholder report, the gross area of the valley floor from Cochiti to San Marcial is 210,000 acres. Of this, the net irrigable area included in the Middle Rio Grande Conservancy District, as set forth in the approved plan for the district (table 5, p. 43 of the Burkholder report) is 123,267 acres, including 22,734 acres of Indian land. There are six Indian Pueblos with grants totaling 28,500 acres within the district. These are Cochiti, Santo Domingo, San Felipe, Santa Ana, Sandia, and Isleta. The irrigated and other

FIGURE 26. San Juan heading, Middle Rio Grande Conservancy District, New Mex.

[illegible] within the district as shown [illegible] the 1936 [illegible] by divisions in table 66.

TABLE 66.—*Irrigated and other [illegible] in Middle Rio Grande Conservancy District, 1936*

[illegible]	[illegible] irrigated	Other water-[illegible] acreage	Total
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	22,819	35,308	58,127
[illegible]	[illegible]	53,149	[illegible]
Socorro	[illegible]	[illegible]	33,072
[illegible]	59,159	128,523	187,682

In the original plan of the Middle Rio Grande Conservancy District, the southern third of Socorro Valley, which is included in the Bosque del Apache and Pedro Armendaris No. 33 grants, was to be a part of the district and to be drained by the district. In the final plan as carried out, however, this area, which extends for about 16 miles from the present southern boundary of the district to San Marcial, was not included. As set forth in the original plan, the area within the limits of this proposed improvement amounted to 14,479 acres, exclusive of river bed, roads, ditches, and rights-of-way, and was classified as 1,112 acres irrigated and 13,367 acres nonirrigated. Of the latter, 11,968 acres were listed as salt grass and bosque. This area in the lower Socorro Valley in naturally divided by the river meanders into four units, two on each side of the river. Those on the north comprise land in the Bosque del Apache grant known as the Elmendorf tract. Those on the south comprise the San Marcial unit on the west side of the river and the Val Verde-La Mesa unit on the east side. The irrigated land of the above mentioned classification in the District's original plan was in the Val Verde-La Mesa unit and was served by what was stated to have been the only irrigation ditch of the whole lower Socorro Valley.

The lower area not included in the Middle Rio Grande Conservancy District has never been drained and the water table over much of it is close to the surface. There is, therefore, a large consumption of water by native vegetation. The 1936 survey showed an area of 16,475 acres upon which water is thus consumed due to natural conditions and 919 acres which were irrigated.

Surveys of the unit in the Bosque del Apache grant were made during the summer of 1936 by the United States Biological Survey to determine the feasibility of developing a migratory water-fowl preserve on the lands. The report of this survey proposes that the Biological Survey acquire the entire Bosque del Apache grant of 53,000 acres and convert it into a Federal refuge, developing about 14,000 acres lying in the river valley for the waterfowl preserve. Portions of the higher bottom lands would be drained to furnish water for about 2,400 acres of controlled ponds while agricultural crops including food-producing grasses would be grown on about 6,000 acres of the drained lands. The latter would be irrigated by indirect diversion from Rio Grande through the canal system of the middle Rio Grande Conservancy District under a water filing acquired with the Grant purchase.

Table 67 lists the Indian Pueblos in the Middle Section and gives their source of water supply.

TABLE 67.—*Indian pueblos in the middle section*

Pueblo	[illegible]	Remarks
Acoma	[illegible]	In Rio Puerco Basin.
[illegible]	[illegible]	[illegible] Conservancy District.
[illegible]	[illegible]	In Middle Rio Grande Conservancy District.
[illegible]	[illegible] Creek	
Laguna	Rio San Jose	In Rio Puerco Basin.
[illegible]	[illegible]	
[illegible]	Rio Pueblo	In Embudo Creek Basin.
[illegible]	Rio Grande	In Middle Rio Grande Conservancy District.
[illegible]	Rio Grande	In Middle Rio Grande [illegible] District.
[illegible]	Pojoaque Creek	Water from Rio Grande also
[illegible]	[illegible]	Water from Rio Chama als[illegible]
[illegible]	Rio Grande	Water from Santa Clara C[illegible]
Santo Domingo	Rio Grande	[illegible] District.
Santa Ana	Rio Grande	Pueblo is [illegible]
[illegible]	Rio Lucero and Rio [illegible]	
[illegible]	[illegible]	
[illegible]	[illegible]	

The Elephant Butte-Fort Quitman Section

The 1936 survey showed the irrigated and other water-consuming areas in the Elephant Butte-Fort Quitman section to be as indicated in table 68.

TABLE 68.—*Irrigated and other water-consuming areas, Elephant Butte-Fort Quitman section, 1936*

Subdivision	Acreage irrigated	Other water-consuming [illegible]	[illegible]
Tributary valleys	[illegible]	8,353	[illegible]
Palomas Valley [1]	880	9,553	[illegible]
[illegible]	15,206	[illegible]	[illegible]
[illegible]	82,923	[illegible]	110,418
[illegible] [2]	70,602	[illegible]	94,433
Total	170,569	82,540	[illegible]

[1] [illegible]
[2] [illegible]

There is little irrigation on tributary streams in this section since, as previously noted, most of the tributaries are arroyos in which water flows only at times of sudden and irregular storms. In the region from San Marcial to the upper end of Rincon Valley there are a few tributaries on the west which have small valley areas along upper reaches at some distance from Elephant Butte Reservoir and Rio Grande below. In these upper reaches there is some flow from springs and occasional storm run-off and this is practically all used for irrigation in the small valleys. Areas thus

irrigated on these tributaries, as shown by the 1936 survey, are given in table 69. The tributaries are listed in downstream order from San Marcial.

Below Elephant Butte Dam, but above and not included in the Rio Grande Project of the Bureau of Reclamation, is the Palomas Valley, with a gross valley floor area of about 10,000 acres. Only a small part of this area is irrigated. As shown by the 1936 survey, it amounted to 830 acres.

TABLE 69.—*Irrigation on Rio Grande tributaries, San Marcial to Rincon Valley, 1936*

Tributary	Acreage irrigated	Remarks
Rio Cañada Alamosa	693	Largely in the vicinity of the town of Monticello.
Cuchillo Negro Creek	215	Largely under Cuchillo community ditch near settlement of Cuchillo.
Las Palomas Creek	409	Largely under Las Palomas community ditch above settlement of Las Palomas.
Las Animas River	227	
Percha Creek	64	Between Kingston and Hillsboro and below the latter.
Total	1,608	

The Rio Grande Project includes the agricultural lands in Rincon and Mesilla Valleys and 40 miles of El Paso Valley below El Paso on the Texas side of the river. The planned irrigated acreage of the project, as indicated in reports of the Bureau of Reclamation, is 155,000 acres. Of this, 88,000 acres are in New Mexico and 67,000 acres in Texas; these are the acreages included respectively in the Elephant Butte Irrigation District and the El Paso County Water Improvement District, the two organizations which represent the water users under the Rio Grande Project. Segregated in accordance with the valleys, Rincon includes 16,000 acres, Mesilla 82,000 acres, and El Paso 57,000 acres of the total. As the figures indicate, 10,000 acres of the Mesilla Valley area are in Texas. All old community ditches were taken over by the Project, reconstructed, enlarged, or extended, and incorporated as parts of the present system of more than 630 miles of main canals and laterals through which the waters released from Elephant Butte Reservoir are distributed. There are diversion dams and permanent diversion works at six points along the river. These are Percha Dam at the head of Rincon Valley, diverting to the Arrey canal; Leasburg Dam at the head of Mesilla Valley, diverting to the Leasburg canal; Mesilla Dam southwest of Las Cruces, diverting to the east side and west side canals; the International Diversion Dam

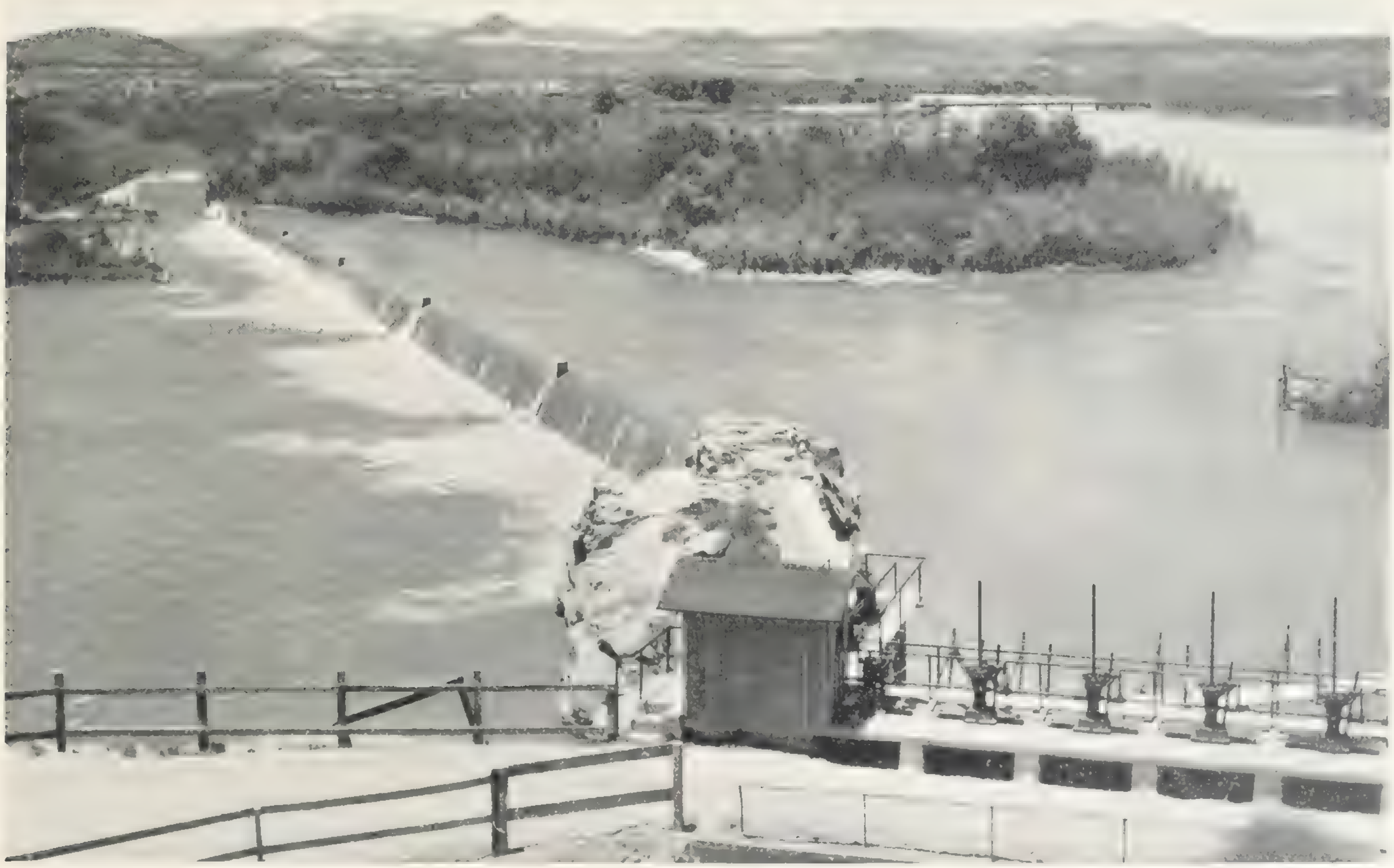
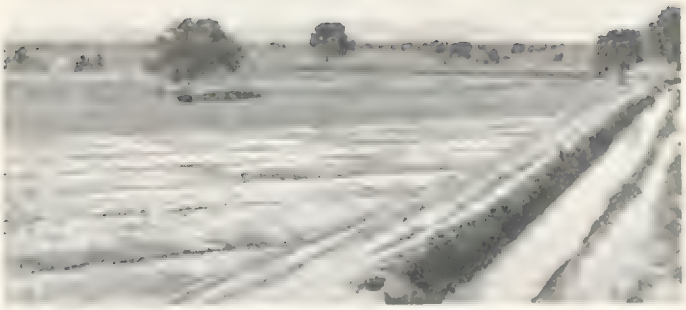


FIGURE 27.—Leasburg Diversion Dam, Rio Grande Project. Head of Mesilla Valley, N. Mex.



[illegible]

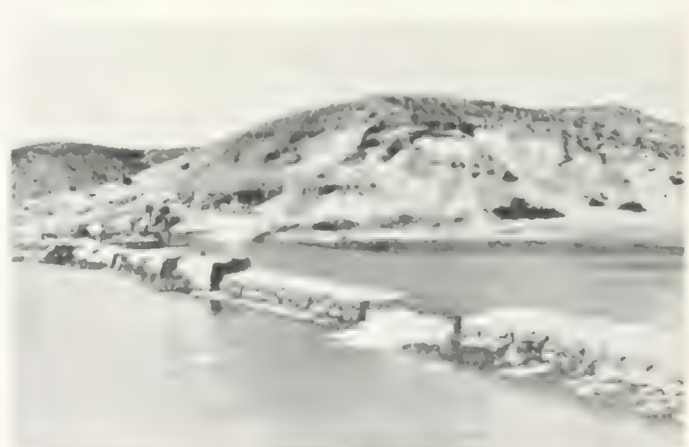
opposite El Paso, diverting to the Mexican Acequia Madre on the west side and to the Franklin canal on the east side; Riverside Heading about 15 miles below El Paso, diverting to the Riverside canal and Franklin feeder; and Tornillo Heading near the town of Fabens, diverting to the Tornillo canal. The drainage system of the Project is completed except for revisions and reconstruction occasioned by the river rectification program of the International Boundary Commission, and it comprises more than 450 miles of deep open drains.

The International Diversion Dam is owned by Mexico and was built to divert water into the Mexican canal. It is at this dam that delivery must be made to Mexico of 60,000 acre-feet annually under the terms of the treaty of 1906. The Bureau of Reclamation is responsible for this delivery, which must be accomplished largely through releases from Elephant Butte Reservoir, more than 125 miles upstream. The channel of the Rio Grande is thus used to carry water both for delivery to Mexico and for canals serving the Rio Grande Project. Below the Mexican Dam the river channel carries water to the Rio Grande Project canals heading below El Paso. In spite of its dual obligation to deliver water to Mexico and to the Rio Grande Project canals, the United States neither owns nor controls this carrying channel from Elephant Butte to the Mexican Dam. Since quantities of water considerably in excess of 60,000 acre-feet must pass the Mexican Dam to supply Project canals below El Paso, and since the United States has no control over Mexican diversion to the Acequia Madre at the west end of the dam, which lies in Mexican territory, it has never been possible to deliver exactly 60,000 acre-feet to Mexico or to determine accurately the extent of the Mexican diversion. As a result of this situation, it is indicated that the diversions by Mexico have exceeded the treaty specifications by substantial amounts. Moreover, there are other Mexican ditches heading on the river below Juarez and having no rights under the treaty, into which water is diverted if and when possible. An estimate of Mexican diversions in the period 1930–36, derived by elimination in a study taking into account all available data of stream flow, diversions, return flow, and arroyo inflow, is given in the section of this report on water uses and requirements.

Since the construction of Elephant Butte Dam, the river channel from it to El Paso has progressively decreased in capacity due to the elimination of large floods and their scouring action, and to the growth of vegetation in former flood channels. As a result, relatively small floods, originating below Elephant Butte Dam chiefly in the western arroyos above Caballo Narrows, coming into the restricted river channel, constitute a distinct menace to the valley lands and to the irrigation structures of the Rio Grande Project. The river channel is, and always has been, unstable and shifting. Below El Paso the International Boundary Commission has been engaged for some time upon a program of river rectification and control in accordance with a convention between the United States and Mexico concluded February 1, 1933; much of the construction work between El Paso and Fort Quitman is complete.

To bring about the control and stabilization of the river channel from Caballo Narrows to El Paso, to obtain flood control storage sufficient to operate and maintain this channel when constructed as well as the present rectified channel below El Paso, and to accomplish control of the delivery of water to Mexico and of diversion by Mexico under the treaty, three projects were proposed by the American section of the International Boundary Commission, namely, Caballo Reservoir, river canalization from Caballo Dam to El Paso, and the American diversion dam and canal.

When Elephant Butte Dam was constructed, gates and six penstock openings were built into it in anticipation of power development. The character of the releases from the reservoir for irrigation preclude development of firm power, but a reservoir below the dam of sufficient capacity to accomplish re-regulation would make it possible. It was therefore proposed by the



[illegible]

Bureau of Reclamation that Caballo Reservoir be given a capacity which would provide both for flood control and for re-regulation such that firm power could be developed at Elephant Butte Dam. An allocation of funds for Caballo Dam was made by the Federal Emergency Administration of Public Works, and in May 1936 work was begun under the direction of the Bureau of Reclamation. As planned, this dam will provide a reservoir of 350,000 acre-feet capacity, of which 100,000 acre-feet will be reserved for flood control. The dam is about 25 miles below Elephant Butte Dam and 2 miles above Percha Diversion Dam. The lands to be flooded are in the Palomas Valley.

The Caballo-El Paso canalization project will provide a rectified normal flow channel with levees set back to provide capacity for the maximum anticipated flood.

Under the American Dam project a diversion dam is being built on Rio Grande just above the Mexican boundary and entirely within the territorial limits of the United States. From this dam, on the Texas side, a 2-mile canal will be built to connect with the present Franklin canal. In this way diversion of water to Rio Grande Project lands of El Paso Valley and delivery to Mexico under the treaty will be controlled.

The acreages within the boundaries of the Rio Grande Project as shown by the 1936 survey are given in table 70.

TABLE 70.—*Acreage irrigated on the Rio Grande project, 1936*

Subdivision:		*Acreage irrigated*
Rincon Valley		15, 206
Mesilla Valley:		
In New Mexico	72, 258	
In Texas	10, 665	
Total		82, 923
El Paso Valley		56, 423
Total		154, 552

Reference to table 92 in the following section of this report, which gives the irrigated acreage of Rio Grande Project, 1930 to 1936, inclusive, as reported by the Bureau of Reclamation, shows a figure for 1936 about 12 per cent lower than the figure for that year as

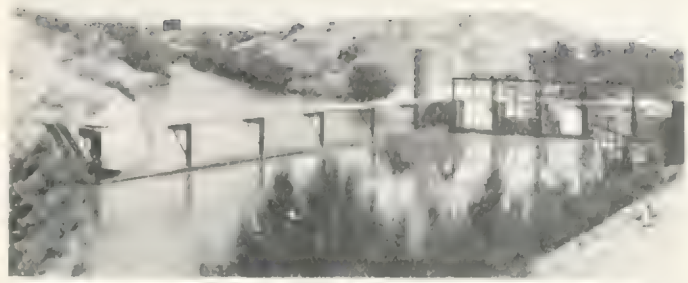


FIGURE 31.—Hudspeth Canal heading and Tornillo wasteway, [illegible] Rio Grande Project.

obtained by the Bureau of Agricultural Engineering and shown in table 70, although the difference between figures for the total acreage of the Project as found by the 1936 surveys of the two bureaus is only about 1 percent. The difference in the irrigated acreage figures is largely due to handicaps under which the Bureau of Agricultural Engineering worked in the early part of the 1936 season, and to greater precision in the Bureau of Reclamation surveys not feasible or necessary in the case of the Bureau of Agricultural Engineering survey. It was required that the latter be planned to cover the entire Upper Rio Grande Basin with a degree of accuracy as needed for the purpose of the Rio Grande joint investigation, and the latter was not such as to require the precision of instrumental surveys. A detailed comparison of the Project acreages as obtained by the two surveys is given in Part III of this report.

The Hudspeth County Conservation and Reclamation district, below and southeast of the Rio Grande Project, is served by an irrigation and drainage system as shown on the map, plate 22. The Hudspeth main canal heads at the lower end of the Tornillo canal of the Rio Grande Project about 12 miles southeast of Fabens and diverts the residual flow of the latter canal. At Alamo Heading on Rio Grande, about 8 miles

FIGURE 30.—Franklin Canal at settling basin and sluiceway, near El Paso. Rio Grande Project.

FIGURE 32.—Main canal, lower Hudspeth district, Texas.

below the end of the Tornillo canal, river flow, consisting chiefly of drainage and return water, is diverted by gravity to the Hudspeth feeder canal which joins the Hudspeth canal a short distance northwest of Fort Hancock. The diversion by the Hudspeth district of the drainage and waste flow from the Rio Grande Project is made under a Warren Act contract. This contract extends only to the return water as it occurs in the normal operation of the Rio Grande Project and puts no obligation upon the latter for delivery of any specific amounts of water. The acreage irrigated from Rio Grande in 1936 in Hudspeth County was 13,579, and this was only about 300 acres more than the irrigated acreage in the Hudspeth district.

On the Texas side of the river between Guayuco Arroyo, which is the terminus of the Hudspeth district canal system, and the canyon below Fort Quitman there is some irrigation by individual landowners, who divert from the river by short gravity ditches or by pumping plants. The total acreage shown to be thus irrigated in 1936 was 526 acres. This included about 200 acres in the Hudspeth district below Guayuco Arroyo.

No data are available on the El Paso Valley acreage irrigated from Rio Grande on the Mexican or Juarez Valley side. Estimates in various reports and in the annual histories of the Rio Grande Project have varied from 25,000 to 40,000 acres.

PART I
SECTION 4.—WATER USES AND REQUIREMENTS

For Irrigation

In the Upper Rio Grande Basin the use of water for irrigation constitutes practically its entire use. Although there is, of course, use by cities and villages throughout the basin, the amount so consumed represents a very small part of the total use in the basin. Use of water for power development is confined to a few small units and is not consumptive. It is the use of water for irrigation and the disposition of it for that purpose which give rise to the problems of the basin with which this investigation is chiefly concerned.

Irrigated and Other Water-Consuming Areas, 1936

It has been mentioned in the preceding section of this report that the Bureau of Agricultural Engineering carried through as one of its assignments on the Rio Grande joint investigation, a complete survey and mapping of the 1936 vegetative cover of the basin. This was done in order to determine by vegetative classification the acreage irrigated in the basin as well as the acreage of all other areas consuming water in appreciable quantities and located within constructed irrigation systems or minor additions and extensions already planned. In the detailed report of the survey given in Part III of this report the data obtained are assembled in three tables, A, B, and C. Table A presents the figures for the part of the Rio Grande Basin in Colorado, table B for the part in New Mexico from the Colorado line to San Marcial, and table C for the part in New Mexico and Texas from San Marcial to Fort Quitman. Table 71 of this section is a summary of the data for the entire Upper Rio Grande Basin. It shows that 2,092,817 acres were mapped. Of this total 988,826 acres were given water artificially, including 923,594 irrigated, 46,319 temporarily out of cropping, and 18,913 in cities, towns, and villages. An area of 1,017,466 acres used water but was not irrigated, including 948,171 of native vegetation, and 69,295 of water and river bed surfaces. Finally, 86,525 acres were in bare lands, roads, rights-of-way, etc.

TABLE 71.—*Irrigated and other water-consuming areas in Upper Rio Grande Basin, 1936*

Major unit	Total area mapped	Agricultural and other lands artificially given water				Other water-using areas, nonirrigated			
		Irrigated in 1936	Temporarily out of cropping	Cities, towns, and villages	Total irrigated "out" and towns	Native vegetation	Water and river bed surfaces	Total nonirrigated	Bare land, roads, rights-of-way, etc.
Total, Upper Rio Grande Basin	2,092,817	923,594	46,319	18,913	988,826	948,171	69,295	1,017,466	86,525
Colorado total	1,446,652	600,243	18,979	6,029	625,251	737,199	13,762	750,961	70,440
Closed basin area	733,425	277,922	8,875	1,034	287,831	404,014	4,010	408,024	37,570
Live area	713,227	322,321	10,104	4,995	337,420	333,185	9,752	342,937	32,870
Southwest area	482,531	270,350	7,228	4,103	281,681	176,191	6,549	182,740	18,110
Southeast area	230,696	51,971	2,876	892	55,739	156,994	3,203	160,197	14,760
New Mexico total	537,894	242,684	21,681	12,097	276,462	193,116	53,591	246,707	14,725
Colorado State line to Buckman	127,729	75,173	4,534	3,110	82,817	31,622	10,956	42,578	2,334
Areas on main stem of Rio Grande	12,878	5,891	374	233	6,498	3,651	2,336	5,987	393
West side tributaries (to and including Rio Chama)	49,011	29,154	1,207	564	30,925	11,645	5,973	17,618	468
East side tributaries	65,840	40,128	2,953	2,313	45,394	16,326	2,647	18,973	1,473
Buckman to south boundary Middle Rio Grande Conservancy District	221,786	76,690	8,323	7,141	92,154	96,507	25,532	122,039	7,593
Areas on main stem of river (Middle Rio Grande Conservancy District)	187,682	59,159	2,980	6,165	68,304	90,401	21,895	112,296	7,082
West side tributaries (all below Rio Chama)	34,104	17,531	5,343	976	23,850	6,106	3,637	9,743	511
Bosque del Apache grant	12,583					10,164	1,970	12,134	449
Bosque del Apache grant to San Marcial	4,811	919	330		1,249	2,617	907	3,524	38
San Marcial to Elephant Butte Dam	26,147					22,071	3,384	25,455	692
Elephant Butte Dam to Texas State line	144,838	89,902	8,494	1,846	100,242	30,135	10,842	40,977	3,619
Palomas Valley	10,383	830	501	304	1,635	7,435	1,190	8,625	[illegible]
Elephant Butte Irrigation District	124,494	87,464	7,362	1,404	96,230	18,604	6,251	24,855	3,409
West Side tributaries	9,961	1,608	631	138	2,377	4,096	3,401	7,497	87
Texas (total)	108,271	80,667	5,659	787	87,113	17,856	1,942	19,798	[illegible]
El Paso County Water Improvement District No. 1	86,676	67,088	3,842	787	71,717	11,957	1,861	13,818	1,141
Hudspeth County	21,595	13,579	1,817		15,396	5,899	81	5,980	219

Diversions by Major Canal Systems, 1936

Gross diversions from Rio Grande in 1936 by major canal systems in the upper basin were measured by the Geological Survey in the San Luis and Middle sections and by the Bureau of Reclamation in the Elephant Butte-Fort Quitman section, as part of the Rio Grande joint investigation. In its report the Bureau of Agricultural Engineering has summarized these diversion data and combined them with the corresponding 1936 acreages served by the canals, to derive the figures for gross diversions per unit of area. The summarization is shown in table 72.

The very wide difference in the figures for diversions per acre irrigated as between canals of the San Luis, Middle, and Elephant Butte-Fort Quitman sections is, of course, mainly due to the wide variation in the amounts of water wasted from the canals below the points of measurement. Data on these wastes in 1936 are incomplete and a full comparison of net diversions is not possible. The gross diversion data are of interest, but they afford little indication of the actual consumption of water and the requirements for it.

Consumptive Use of Water

One of the more important elements to be determined in any study of the use of water for irrigation is the "consumptive use" or the volume of water that is actually consumed within a given area and lost to the basin. Under the Rio Grande joint investigation the study and determination of the consumptive use of water in the upper basin and the consumptive requirements of its major units were assigned to the Bureau of Agricultural Engineering. The investigation of the bureau included a complete review of previous studies by various investigators, and field work in 1936 of two types: (1) Consumptive use-of-water studies on large representative areas, and (2) evapo-transpiration measurements by means of tank and soil-moisture experiments. The results are reported in detail in Part III, and salient features of the report are briefly reviewed in the following paragraphs.

Definitions.—The following definitions of consumptive use were used by the Bureau of Agricultural Engineering in its study:

Consumptive use (Evapo-transpiration): The sum of the volumes of water used by the vegetative growth of a given area in transpiration or building of plant tissue and that evaporated from adjacent soil, snow, or intercepted precipitation on the area in any specified time.

Valley consumptive use: The sum of the volumes of water absorbed by and transpired from crops and native vegetation and lands upon which they grow, and evaporated from bare land and water surfaces in the valley; all amounts measured in acre-feet per 12-month year on the respective areas within the exterior boundaries of the valley.

The valley consumptive use (K) is equal to the amount of water that flows into the valley during a 12-month year (I) plus the yearly precipitation on the valley floor or project area (P) plus the water in ground storage at the beginning of the year (G_s) minus the

TABLE 72.—*Gross diversions by major canal systems in upper Rio Grande Basin, 1936*

[illegible]	Area mapped in 1936, acres	[illegible] Irrigated	Temporarily out of cropping	Towns, etc.	Total	1936 canal diversions, acre-feet Total	[illegible] irrigated	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	(4)	[illegible]	[illegible]	[illegible]	(8)	(9)	[illegible]
[illegible]									
[illegible]	142,196	111,844	[illegible]	11	115,516	182,600	[illegible]	[illegible]	1.28
[illegible]	91,280	46,267	2,775	397	49,439	45,710	.99	.92	.48
[illegible]	29,471	12,043	[illegible]	125	13,144	10,900	.91	.83	.37
[illegible]	40,524	8,234	1,159	14	9,407	21,790	[illegible]	2.31	[illegible]
[illegible]	33,512	24,382	371	19	24,772	37,520	1.54	1.51	[illegible]
[illegible]	64,311	20,794	[illegible]	12	21,731	57,370	[illegible]	2.64	.89
[illegible]									
Middle Rio Grande Conservancy District	187,682	59,159	[illegible]	[illegible]	68,304	619,989	10.48	9.08	3.30
[illegible]	19,430	5,208	[illegible]	401	5,778	75,058	[illegible]	12.99	3.86
[illegible]	[illegible]	22,819	913	[illegible]	[illegible]	[illegible]	[illegible]	8.40	[illegible]
Belen division	[illegible]	[illegible]	1,165	530	25,590	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	7,237	733	[illegible]	8,963	[illegible]	9.10	[illegible]	[illegible]
[illegible]									
[illegible]	[illegible]	[illegible]	11,204	2,191	167,947	[illegible]	6.26	5.77	4.59
[illegible]	27,914	15,206	2,129	[illegible]	[illegible]	78,410	5.16	[illegible]	[illegible]
Mesilla Valley	[illegible]	[illegible]	[illegible]	1,523	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	558	[illegible]	[illegible]	8.38	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.57

[illegible] main stem of Rio Grande
[illegible]

amount of water in ground storage at the end of the year (G_e) minus the yearly outflow (R): all amounts measured in acre-feet. The consumptive use of water per acre of irrigated land is equal to (K) divided by irrigated area (A_i); and consumptive use per acre of the entire valley floor is equal to (K) divided by the entire valley area. The unit is expressed in acre-feet per acre.

Stream-flow depletion: The amount of water which annually flows into a valley, or upon a particular land area (I), minus the amount which flows out of the valley or off from the particular land area (R) is designated "stream-flow depletion" (I−R). It is usually less than the consumptive use and is distinguished from consumptive use in the Rio Grande studies.

Past investigations.—The results of previous studies by various investigators are summarized in table 73. It will be noted that there is marked variability in the stream-flow depletion estimates for the same or approximately the same areas. This is not unusual. Precise estimates have been and are difficult, because there are many variable factors influencing consumptive use and stream-flow depletion. Some variability in the estimates may be attributed to dissimilar conditions under which the determinations were made and to lack of specific definitions.

Bureau of Agricultural Engineering investigations.—The results of the consumptive use and stream-flow depletion determinations of the Bureau of Agricultural Engineering by inflow-outflow and other methods applied to representative areas or tracts in the upper basin are summarized in table 74. The location and nature of the many evapo-transpiration stations which were established and maintained are shown in table 75. There is no attempt here to summarize the results

TABLE 73.—*Consumptive use of water in Upper Rio Grande Basin as derived from previous studies of various investigators*

Date	Investigator	Area included	Consumptive use in acre-feet per irrigated acre per year	Stream-flow depletion per irrigated acre per year	Remarks
[illegible]	R. J. Tipton	Southwest area—San Luis Valley		[illegible]	Average, 1921-29.
1930	do	Conejos area—San Luis Valley		2.58	Do.
1930	do	Southwest area minus Conejos, San Luis Valley		1.93	Do.
1930	do	North area—San Luis Valley		2.06	Do.
[illegible]	do	Closed basin irrigated from Rio Grande		1.2	
1933	do	Closed basin irrigated from other streams		1.5	
1933	R. J. Tipton and F. C. Hart	Bowen-Carmel—San Luis Valley	2.30	1.42	Average, 1930, 1931, and 1932.
1931	H. W. Yeo and R. F. Black	Water District 20, San Luis Valley		2.01	Average, 1915–28.
1931	Yeo and Black	Water District 22, San Luis Valley		2.67	Average, 1921–28.
1931	do	Entire San Luis Valley	3.17	2.10	Average, 1918–27.
1936	C. R. Hedke and Bureau of Agricultural Engineering.	do		2.52	Average, 1900–23.
1928	R. I. Meeker and L. T. Burgess	Mesilla Valley		3.5	Average, 1923-27.
[illegible]	Meeker and Burgess	Elephant Butte to El Paso		3.15	Average, 1920–27.
1928	do	El Paso to Fort Quitman		[illegible]	Average, 1923-27.
1928	E. P. Osgood	Elephant Butte to Fabens		[illegible]	Average, 1919–27.
			Total stream-flow depletion in 1,000 acre-feet units		
[illegible]	[illegible]	Middle Valley	508		Average, 1895-1918
1925	C. R. Hedke	do	565		1925.
1927	[illegible]	do	510		Average, 1895-1926.
1927	do	do	535		By comparison to Mesilla Valley.
1929	R. G. Hosea	do	481		Comparison to Mesilla Valley.
1932	E. B. Debler	do	[illegible]		Do.
1932	do	do	[illegible]		By integration—present.
1928	E. P. Osgood	Elephant Butte to Fabens	[illegible]		1927.
1924	E. B. Debler and A. W. Walker	Rio Grande project	787		1923 and previous records.
[illegible]	R. G. Hosea	do	[illegible]		Average, 1923-27.

TABLE 74.—*Consumptive use of water by representative areas in Upper Rio Grande Basin as derived by Bureau of Agricultural Engineering*

Area or tract	Total acreage	Irrigated acreage	Period covered	Consumptive use [1] in acre-feet per— Irrigated acre	Consumptive use [1] in acre-feet per— Acre of total	Stream-flow depletion in acre-feet per irrigated acre per year	Remarks
Southwest—San Luis Valley	400,000	219,900	1925–35, inclusive	3.02	1.66	1.92	11-year averages.
Do	400,000	224,000	1936	3.28	1.83	1.91	
Central Southwest—San Luis Valley	114,000	61,000	1936	[illegible]	1.80	1.55	
Bowen-Carmel, San Luis Valley	20,000	14,000	1936	2.75	1.86	1.27	
Isleta-Belen, Middle Valley	17,500	9,000	April–December 1936	4.46	2.28	3.39	Inflow-outflow method.
Do	21,074		1936		2.73		Integration method.
Mesilla Valley	109,000	65,814	1919–35	[illegible]	2.73	3.30	17-year averages.
Do	110,418	82,925	1936	3.66	[illegible]	2.67	
Middle Valley				4.10			Estimate using Hedke heat units method.

[1] Includes consumption of precipitation.

TABLE 75.—*Evapo-transpiration and soil-moisture sampling stations established and maintained by Bureau of Agricultural Engineering in Upper Rio Grande Basin in 1936*

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	1 wheat tank; 1 potato tank; U. S. Weather Bureau class A evaporation pan; rain gage; anemometer.
[illegible]	[illegible]	1 tule tank; 2 meadow grass tanks; U. S. Weather Bureau class A evaporation pan; rain gage; anemometer.
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	Soil-moisture sampling plots in orchard, alfalfa field, and vineyard.
[illegible]	[illegible]	Soil-moisture sampling in native-vegetation areas near geological survey [illegible]
Los Poblanos ranch	[illegible]	[illegible]
[illegible]	Adjacent to river at Isleta, Middle Valley	[illegible] Bureau class A evaporation pan; rain gage; anemometer
[illegible]	El Vado Dam on Chama River, Middle Section	U. S. Weather Bureau class A evaporation pan; rain gage; anemometer, thermometers. Cooperation U. S. Weather Bureau and Middle Rio Grande conservancy district.
[illegible]	Middle Rio Grande conservancy district yard at [illegible]	U. S. Weather Bureau class A evaporation pan; rain gage.
State College	[illegible]	Soil-moisture sampling plots; cotton at agronomy farm, field EC and field 9W; alfalfa at horticultural farm.
[illegible]	[illegible]	2 cotton tanks; 2 alfalfa tanks
[illegible]	[illegible]	2 cattail tanks; 1 salt grass tank; U. S. Weather Bureau class A evaporation pan; rain gage.

TABLE 76.—*Units assumed in estimating consumptive water requirements, in acre-feet per acre, San Luis Valley, Colo.*

Location	Irrigated lands			Native vegetation			Miscellaneous			
	Alfalfa, clover	Native hay, pasture	Miscellaneous crops	Grass	Brush	Bosque, [illegible]	[illegible] towns, villages	[illegible] rarily out of [illegible]	Water surfaces	[illegible]
[illegible]										
[illegible]	[illegible]	1.5	[illegible]	[illegible]	1.3	3.8	1.5	1.5	3.5	[illegible]
[illegible]	2.5	2.0	[illegible]	1.5	2.0	3.8	1.5	[illegible]	3.5	[illegible]
[illegible]	2.5	2.0	1.5	1.5	1.8	3.8	1.5	1.5	3.5	[illegible]
Southwest area:										
South Fork, Schraders, Pinos Creeks, and areas above	2.0	1.5	[illegible]	[illegible]	.8	3.5	[illegible]	1.5	3.3	[illegible]
Monte Vista canal, Empire canal, and small canals	2.5	[illegible]	[illegible]	1.5	1.5	3.8	1.5	1.5	3.5	[illegible]
Alamosa Creek, La Jara Creek, and Terrace Irrigation District	2.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.5	1.5	3.5	[illegible]
Conejos River and tributaries, San Antonio River, and Los Pinos [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.5	1.5	[illegible]	[illegible]
Rio Grande canal, San Luis canal, and small canals (south closed [illegible])	2.5	2.0	1.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Southeast area:										
[illegible]	2.2	1.5	1.5	1.0	1.0	3.8	1.5	1.5	[illegible]	[illegible]
[illegible]	2.2	1.5	1.5	1.0	1.0	3.8	1.5	1.5	[illegible]	[illegible]
[illegible]	[illegible]	1.5	1.5	1.0	1.0	3.8	1.5	[illegible]	3.5	[illegible]

TABLE 77.—*Estimate of consumptive water requirements in the San Luis Valley, Colo. (including precipitation), based on 1936 acreages*

[illegible]	Irrigated lands			Native vegetation			[illegible]			[illegible]		
	[illegible]	Acre-feet	Acre-feet per acre	[illegible]	[illegible]	[illegible]	[illegible]	Acre-feet	Acre-feet per acre	[illegible]	Acre-feet	[illegible]
Closed basin area:												
[illegible]	171,182	[illegible]	1.59	[illegible]	[illegible]	1.22	35,978	[illegible]	0.95	[illegible]	[illegible]	1.34
[illegible]	56,792	101,212	1.78	4,227	8,668	2.05	4,008	[illegible]	1.51	[illegible]	[illegible]	1.78
Alamosa County	[illegible]	[illegible]	2.04	176,109	[illegible]	[illegible]	11,503	14,852	[illegible]	237,560	417,058	1.76
[illegible]	[illegible]	[illegible]	1.71	401,014	[illegible]	[illegible]	51,489	55,197	1.07	733,425	1,111,641	1.52
Southwest area:												
South Fork, Schraders, Pinos Creeks, and [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.51	2,823	5,310	[illegible]	[illegible]	[illegible]	1.71
Monte Vista canal, Empire canal, and [illegible]	[illegible]	165,362	1.95	77,809	132,693	1.71	9,404	12,678	[illegible]	172,064	310,733	1.81
[illegible]	[illegible]	88,409	1.80	43,339	71,113	1.64	[illegible]	[illegible]	1.34	100,420	170,345	1.70
Conejos River and tributaries, San Antonio [illegible]	82,389	132,871	1.61	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.62
Rio Grande canal, San Luis canal, and small canals (south closed area)	33,654	64,575	1.92	26,000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	119,358	[illegible]
Entire area	270,350	482,833	1.79	[illegible]	[illegible]	[illegible]	35,990	[illegible]	[illegible]	[illegible]	841,494	[illegible]
Southeast area:												
[illegible]	[illegible]	[illegible]	1.61	73,173	[illegible]	1.07	[illegible]	7,436	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	4,390	1.64	6,286	11,412	[illegible]	619	1,063	1.72	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1.63	77,535	79,674	[illegible]	15,157	18,697	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1.63	156,994	169,022	1.08	21,731	[illegible]	[illegible]	[illegible]	[illegible]	1.22
Total	600,243	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

obtained at these stations; reference is made to Part III for a description of the work and a complete statement of the results.

The Bureau of Agricultural Engineering on the basis of its own work and that of others proposed estimates of the present consumptive requirements for water in the various sub-basins of the Upper Rio Grande Basin as shown in tables 76 to 81, inclusive. These embody the consumptive use determinations as derived by the so-called integration method; that is, based on all available experience and judgment, unit values of consumption (acre-feet per acre) are assigned to the various classes of vegetative and other cover, taking into account the location of the latter within the basin with respect to altitude and latitude. These units are then multiplied by the corresponding class acreages to derive the total consumptive use in acre-feet. Since the unit figures represent consumption which is to be supplied from any and all sources of water, the total figures derived include precipitation and ground-water contributions as well as stream-flow depletion.

TABLE 78.—*Units assumed in estimating consumptive water requirements, in acre-feet per acre, Colorado-New Mexico State line to San Marcial, N. Mex.*

Location	Irrigated lands			Native vegetation			Miscellaneous			
	Alfalfa	Native hay, pasture	Miscellaneous	Grass	Brush	Bosque, trees	Cities, towns, villages	Temporarily out of cropping	Water surfaces	Bare land
State line to Rinconada [1]										
Rinconada to Embudo	3.5	2.5	1.5	2.5	2.5	4.0	2.0	2.0	3.7	1.0
Embudo to Santa Fe County line	3.5	2.5	1.5	2.5	2.5	4.0	2.0	2.0	3.7	1.0
Santa Fe County line to Buckman	3.5	2.5	1.5	2.5	2.5	4.0	2.0	2.0	3.7	1.0
Middle Rio Grande Conservancy District:										
Cochiti division	4.0	2.5	2.0	2.5	3.0	5.0	2.0	2.0	4.3	1.0
Albuquerque division	4.0	2.5	2.0	2.5	3.0	5.0	2.0	2.0	4.3	1.0
Belen division	4.0	2.5	2.0	2.5	3.0	5.0	2.0	2.0	4.3	1.0
Socorro division	4.0	2.5	2.0	2.5	3.0	5.2	2.0	2.0	4.5	1.0
Bosque del Apache grant	4.0	2.5	2.0	2.5	3.5	5.8	2.0	2.0	5.0	1.0
Bosque del Apache to San Marcial	4.0	2.5	2.0	2.5	3.5	5.8	2.0	2.0	5.0	1.0

[1] Canyon section.

TABLE 79.—*Estimate of consumptive water requirements, main stem of Rio Grande, Colorado-New Mexico State line to San Marcial, N. Mex. (including precipitation), based on 1936 acreages*

Location	Irrigated lands			Native vegetation			Miscellaneous [1]			Total area mapped		
	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre
State line to Rinconada [2]												
Rinconada to Embudo	191	349	1.83	31	78	2.50	156	540	3.46	378	967	2.56
Embudo to Santa Fe County line	4,894	10,037	2.05	2,243	6,615	2.95	2,212	6,608	2.99	9,349	23,260	2.49
Santa Fe County line to Buckman	806	1,823	2.26	1,377	5,030	3.65	968	3,102	3.20	3,151	9,955	3.16
Middle Rio Grande Conservancy District:												
Cochiti division	5,208	12,549	2.41	11,232	40,756	3.63	2,999	8,611	2.87	19,439	61,916	3.19
Albuquerque division	22,819	61,608	2.70	23,495	81,322	3.46	11,813	35,902	3.04	58,127	178,832	3.08
Belen division	23,895	65,188	2.73	40,794	123,322	3.02	12,355	36,421	2.95	77,044	224,931	2.92
Socorro division	7,237	18,124	2.50	14,880	58,899	3.96	10,955	40,156	3.67	33,072	117,179	3.54
Bosque del Apache grant				10,164	56,364	5.55	2,419	10,299	4.26	12,583	66,663	5.30
Bosque del Apache to San Marcial	919	2,539	2.76	2,617	14,137	5.40	1,275	5,233	4.10	4,811	21,909	4.55
Total	65,969	172,217	2.61	106,833	386,523	3.62	45,152	146,872	3.25	217,954	705,612	3.24

[1] Cities, towns, and villages; land temporarily out of cropping; water surfaces—pooled water, river and canal surfaces and exposed beds; bare land, roads, rights-of-way etc.
[2] Canyon section.

TABLE 80.—*Units assumed in estimating consumptive water requirements, in acre-feet per acre, San Marcial, N. Mex., to Fort Quitman, Tex.*[1]

Location	Irrigated lands				Native vegetation			Miscellaneous			
	Cotton	Alfalfa	Native hay, pasture	Miscellaneous crops	Grass	Brush	Bosque, trees	Cities, towns, villages	Temporarily out of cropping	Water surfaces	Bare land
San Marcial to Elephant Butte Dam					2.5	3.2	5.8			5.5	0.8
Palomas Valley (Elephant Butte Dam to Apache Canyon)		4.0	2.5	2.0	2.5	3.2	5.0	2.0	2.0	4.5	.8
Rincon Valley (in Sierra and Dona Ana Counties)	2.5	4.0	2.5	2.0	2.5	3.0	4.8	2.0	2.0	4.5	.7
Mesilla Valley in New Mexico and Texas	2.5	4.0	2.5	2.0	2.5	2.8	4.8	2.0	2.0	4.5	.7
El Paso division, Rio Grande project	2.5	4.2	2.5	2.0	2.5	3.0	4.8	2.0	2.0	4.5	.7
Hudspeth County Conservation and Reclamation District No. 1	2.5	4.2		2.0	2.5	3.2	5.0		2.5	4.5	.7

[1] Results of Bureau of Plant Industry salinity studies were not available when these estimates were made.

[illegible]

[illegible]	[illegible]			[illegible]			Miscellaneous [1]			Total area mapped		
	[illegible]	Acre-feet	Acre-feet per acre	Acres	[illegible]	Acre-feet [illegible]	[illegible]	Acre-feet	[illegible]	Acres	[illegible]	Acre-feet [illegible]
[illegible]				22,071	114,796	5.20	[1] 20,750	110,873	[illegible]	[2] 42,821	225,669	5.27
[illegible]	850	[illegible]	2.42	7,435	25,868	3.48	2,118	7,063	3.34	10,383	[illegible]	3.37
[illegible]	[illegible]	[illegible]	2.65	7,310	27,955	3.82	[illegible]	16,817	3.12	27,914	85,118	3.05
[illegible]	[illegible]	[illegible]	2.74	13,198	43,199	3.27	14,297	34,735	[illegible]	110,418	305,299	[illegible]
[illegible]	[illegible]	163,105	[illegible]	10,053	[illegible]	3.25	[3] 6,362	14,927	[illegible]	[3] 72,838	210,686	[illegible]
Hudspeth County Conservation and Reclamation [illegible]	[illegible]	[illegible]	2.62	[illegible]	22,567	3.83	2,117	5,061	2.39	21,595	63,259	2.93
[illegible]	[illegible]	[illegible]	2.83	[illegible]	[illegible]	[illegible]	[1,3] 51,042	189,476	3.71	[1,3] 285,969	924,973	3.23

[1] [illegible]
[2] Includes water surface area of Elephant Butte Reservoir (16,674 acres) as averaged for June 1936.
[3] Exclusive of city of El Paso (6,210 acres).

NOTE.—Results of Bureau of Plant Industry salinity studies were not available when estimates were made

Basin Totals of Supply and Use

The data for total water production in the Upper Rio Grande Basin as derived in a previous section, and the consumptive use data of tables 76 to 81 combined with the acreage data of tables A, B, and C of Part III, afford a comparison of figures for total supply and consumption and an approximation of basin surpluses or deficiencies. Such a comparison is shown in table 82. For each of the three major sections of the upper basin, San Luis, Middle, and Elephant Butte-Fort Quitman, and for the whole upper basin, there are shown (1) the total irrigated and other water-consuming acreage (native vegetation, etc.) as found by the 1936 survey, (2) the consumptive use of water as measured by stream-flow depletion, and (3) the derived weighted average unit stream-flow depletion. The consumption is then compared to the water supply as measured by the natural run-off to the sections and to the entire basin, for a normal, maximum, and minimum run-off year. Since there is no return to Rio Grande from the closed basin (except for that in the Rio Grande drain) any surplus to Rio Grande in the San Luis section must be derived as the run-off to the southwest and southeast areas less the consumption (stream-flow depletion) in those areas and the consumption in the closed basin served from Rio Grande. The acreage shown in the table for San Luis section is therefore that for the southwest and southeast areas plus that in the closed basin served from Rio Grande, and the consumption shown is that corresponding to this acreage. The acreage figures of table 82 are taken from tables A, B, and C of Part III and the consumption figures partly from tables 76 to 81 and partly by further derivation combining the data of the consumptive use and acreage tables where the former do not give the complete data; for example, the consumption by the closed basin area served from Rio Grande and the consumption by the [illegible] Middle and Elephant Butte-Fort Quitman sections. Estimates of acreage and consumption in Mexico were also included in an endeavor to make the comparisons complete for the upper basin. The data of tables 76 to 81 represent total consumption, including precipitation. In deriving the stream-flow depletion figures of table 82, therefore, correction was made for precipitation by subtracting from the unit consumption figures, 0.6 for San Luis Valley and 0.7 for the main river valleys and 1.0 for the tributary valleys of the Middle and Elephant Butte-Fort Quitman sections.

TABLE 82.—*Comparison of water supply and stream-flow depletion by irrigation, Upper Rio Grande Basin*

No.	[illegible]	San Luis [illegible]	Middle section	Elephant Butte-Fort Quitman [illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	Consumptive use (stream flow [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	Unit stream flow depletion-[illegible]	1.00	2.09	[illegible]	1.54
	[illegible]				
4	Water supply—total natural run-off, acre-feet	[4] 1,379,000	1,333,000	[illegible]	[illegible]
5	Surplus or deficiency, item 4 — item 2, acre-feet	[illegible]	[illegible]	−720,000	177,000
	[illegible]				
[illegible]	Water supply—total natural [illegible]	[illegible]	2,080,000	614,000	1,283,000
[illegible]	[illegible]	[illegible]	1,312,000	−271,000	1,583,000
	MINIMUM YEAR (1902)				
[illegible]	[illegible] total natural [illegible]	[4] 507,000	[illegible]	[illegible]	1,071,000
[illegible]	[illegible]	−540,000	−316,000	−773,000	−1,629,000

[illegible]

For San Luis and Middle sections, table 82 shows surpluses in the maximum and normal years and deficiencies in the minimum year. Elephant Butte-Fort Quitman section shows deficiencies in all years. For the entire upper basin, a surplus of 177,000 acre-feet is shown for the normal or mean year. Considering the nature of the derivation of this figure and the many factors involved, it is in fair agreement with the 13-year mean outflow of Rio Grande at Fort Quitman, 1924–36, which is 211,000 acre-feet. In the maximum year there is a basin surplus of over a million and a half acre-feet, and in the minimum year an equivalent or slightly greater deficiency.

In the data of table 83, the water supply and stream-flow depletion figures are used to show a comparison of the water "beneficially" consumed and that consumed "otherwise." For the purposes of this comparison beneficial consumption is taken to be that by the irrigated acreage only. Of the water consumed otherwise there may be certain uses such as reservoir evaporation, for example, which are not necessarily nonbeneficial but which would not be classed as directly beneficial. However, besides many unavoidable consumptive losses, the "otherwise" uses include many which are avoidable. These may be consumption by native vegetation which could be prevented advantageously by drainage, transmission losses which could be reduced economically by canal improvements, excess use associated with the practice of careless irrigation methods, or operation wastes.

TABLE 83.—*Comparison of directly beneficial and other consumptive uses of water in irrigation, Upper Rio Grande Basin*

[Unit, 1,000 acre-feet except as noted]

Basin unit	Total annual inflow of run-off, 46-year mean	Total acreage irrigated, 1936, 1,000-acre units	Stream-flow depletion by irrigated acreage, 1936; directly beneficial consumptive use — Unit, acre-feet per acre	Stream-flow depletion by irrigated acreage, 1936; directly beneficial consumptive use — Total	Total annual outflow of run-off, 46-year mean	Beneficial use plus outflow (5)+(6)	Other consumptive uses (2)−(7)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
San Luis section	1,567	600	1.14	684	[1] 448	1,132	435
Middle section	[2] 1,781	[3] 153	1.50	230	[4] 1,031	1,261	520
Elephant Butte-Fort Quitman section	[5] [illegible]	[6] 201	2.30	462	[7] 211	673	523
Upper Rio Grande Basin		954	1.44	1,376			1,478

[1] Mean annual outflow at Lobatos with present development San Luis Valley.
[2] Lobatos outflow 448,000 plus Middle section production 1,333,000 acre-feet.
[3] 66,000 acres on main stem of Rio Grande and 87,000 acres in tributary valleys.
[4] Mean annual outflow at San Marcial with present development San Luis Valley.
[5] San Marcial outflow 1,031,000 plus Elephant Butte-Fort Quitman section production 165,000 acre-feet.
[6] Includes estimate of 30,000 acres in Mexico.
[7] Mean outflow at Fort Quitman 1924 to 1936, inclusive.

In explanation of table 83, it is shown for San Luis section, for example, that the total irrigated acreage in 1936 was 600,000 acres, which consumed (depleted the stream flow) an estimated 684,000 acre-feet. This is the directly beneficial consumption in the section. These data are taken from table 77 with a correction to the unit consumption for irrigated lands, as given therein, of 0.6 acre-foot per acre for precipitation, in order to derive stream-flow depletion. With present development in San Luis Valley it is estimated that the mean outflow at Lobatos, 1890–1935, would have been 448,000 acre-feet (table 18). The total of directly beneficial consumption and outflow is therefore 1,132,000 acre-feet, and this subtracted from the mean total inflow to the valley of 1,567,000 acre-feet leaves 435,000 acre-feet consumed annually on areas other than the irrigated acreage. A portion of this large loss can be recovered by drainage. Similarly, the "other consumptive uses" derived for the Middle and Elephant Butte-Fort Quitman sections are, respectively, 520,000 and 523,000 acre-feet, making the basin total for this consumption or loss, 1,478,000 acre-feet. This is a little more than the total basin consumption by the irrigated acreage, shown as 1,376,000 acre-feet. In other words, of the total stream-flow depletion in the basin, about half is beneficially consumed by the irrigated acreage and the other half is represented by losses, some of which are avoidable.

Diversion Requirements of Major Units

Beyond knowledge of the consumptive use of water in the Upper Rio Grande Basin, it is essential to any adjustments which may be proposed for an equitable division of the water between the three sections of the basin, that the requirements of the major units of those sections in terms of the necessary diversion demand upon the stream flow be known. In San Luis Valley this means the demand upon Rio Grande at or above Del Norte to satisfy the requirements of the area served by Rio Grande and the demand upon Conejos River to satisfy the area served by that stream. The demands upon other streams of San Luis Valley are not of concern in the present consideration since other than by occasional flood flows these streams contribute practically no water to the flow of Rio Grande leaving the valley. In the Middle section the essential requirement is the demand upon Rio Grande at Otowi Bridge to serve the Middle Rio Grande Conservancy District, and in the Elephant Butte-Fort Quitman section it is the demand upon Elephant Butte Reservoir to serve the Rio Grande Project and fulfill the treaty obligation to Mexico.

The San Luis section.—Rio Grande Area.—For the area served from Rio Grande in San Luis Valley, the diversion demand was derived from the acreage and consumptive use figures of tables A of Part III and 76, and the return flow data as given under the caption of "return water" in the previous section of this report on

water supply. From table A the irrigated acreage in 1936 was 306,000 acres. Due to the current subnormal water supply, this may have been below average although there are no comparable data for previous years to provide a comparison. To make some allowance for this possibility as well as to include certain of the other water-consuming areas which are served unavoidably, the area of 306,000 acres was increased by 15 percent to a round figure of 350,000 as the acreage irrigated from Rio Grande on which the diversion demand was based. From the data of tables A and 76, the average unit consumptive use of the crops included in the area of 306,000 acres irrigated from Rio Grande in 1936 was 1.9 acre-feet per acre. Subtracting a precipitation allowance of 0.6 foot from this figure and applying the resulting unit stream-flow depletion to 350,000 acres gives 455,000 acre-feet as the total stream-flow depletion. To get the diversion demand there must be added to this figure the total of indivertible waste and return flow. In the portion of this report dealing with return flow it is shown that the return, including waste, in 1936 from Rio Grande diversions, exclusive of those to the closed basin, amounted to 36 percent of those diversions. From this and the other return-flow data given, it was concluded that a return of 30 percent might be conservatively selected in deriving the diversion demand. Application of this percentage gave a demand of 650,000 acre-feet. This was then taken as the yearly requirement for diversion from Rio Grande for the irrigation of 350,000 acres. By way of comparison, the mean of the annual diversions from Rio Grande below the Del Norte gage in the period 1930–36, inclusive, was 501,000 acre-feet. The maximum diversion in this period was that in 1932, amounting to 729,000 acre-feet.

Use of the estimated demand of 650,000 acre-feet in subsequent reservoir operation studies required that its monthly distribution be established as well as the total of return flow to Rio Grande to be anticipated, and its monthly distribution. In the succeeding section of this report on storage development, mention is made of an ideal monthly distribution for Rio Grande diversions in San Luis Valley developed by R. J. Tipton, consultant to the Colorado State Engineer. This was derived from an extensive compilation of the diversions of San Luis Valley canals having old priorities and from the distribution in other comparable regions having adequate storage control. This ideal distribution was taken as the basis for monthly distribution of the diversion demand as developed in this report, both for the area served from Rio Grande and that under the Conejos River. The monthly distribution of the 650,000 acre-feet demand is shown in table 84.

From the data of table 36 and tables 40 to 42 in the section of this report on return water, the total return to the river both above and below Alamosa from Rio Grande diversions is indicated to have been 16.0 percent of the total Rio Grande diversions in 1934, 16.1 percent in 1935, and 19.6 percent in 1936. Assuming that the data of these last 3 years may be taken as a fair index (beginning with 1934 there appears to have been an increase in return water) of the return, a figure of 16 percent was adopted to represent the proportion of total Rio Grande divisions returned to the river. The monthly distribution of return flow has been erratic in the past, depending on monthly diversions, which, in turn, have been dependent on practically unregulated stream flow. With storage regulation and distribution of diversions more nearly in accordance with the ideal monthly demand the monthly distribution of return flow would without doubt show a corresponding uniformity. To derive such a distribution, the computed returns, by months, during the years 1934 to 1936 were compared to the corresponding monthly diversions and the relations so obtained used as the basis for estimate of the return flow and its distribution under the ideal diversion distribution. The resulting distribution is shown in table 84. For a comparison, the actual distribution as indicated by the mean of the return data for 1934, 1935, and 1936 is shown in table 38 of the previous section on return water.

TABLE 84.—*Monthly distribution of estimated diversion demand and resulting return flow, Rio Grande and Conejos areas, San Luis Valley*

[illegible]

Month	[illegible] diversions				[illegible]			
	Diversion demand on Del Norte		Return flow to [illegible] percent of diversions		[illegible]			Return flow [illegible] cent of diver[illegible]
					[illegible] mouth San Antonio	[illegible] tonio	[illegible]	
(1)	(2)	[illegible]	[illegible]	[illegible]	[illegible]	(7)	[illegible]	[illegible]
	[illegible]		[illegible]					
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	17	[illegible]	8	8	[illegible]	[illegible]	[illegible]	6
[illegible]	[illegible]	[illegible]	[illegible]	20	8	[illegible]	[illegible]	15
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8	[illegible]	[illegible]	15
[illegible]	18	117	17	[illegible]	[illegible]	36	[illegible]	14
[illegible]	[illegible]	33	12	11	[illegible]	[illegible]	[illegible]	10
October	[illegible]	13	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0	[illegible]	5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible] by Conejos storage only.

[illegible]
Columns (6), [illegible] of column (2).
[illegible]

Conejos Area.—The diversion demand derived for the Conejos area is that upon the Conejos River at Mogote to serve the area now irrigated from the Conejos and the inflow from San Antonio River. This is the area which would be benefited by proposed storage on the Conejos. The actual stream-flow depletion by this area is given by subtracting the outflow as measured at the mouth of Conejos River from the inflow as measured on Conejos River at the Mogote gage and on San Antonio River at its mouth. The period for which records of all three stations are available is from 1923 to 1936. In this period the mean annual stream flow depletion was 154,500 acre-feet. Extending the records by estimates to include the period 1911–35 (the period used subsequently in reservoir operation studies), the mean annual stream-flow depletion derived for this period is 157,000 acre-feet.

The irrigated and other water-consuming area under the Conejos as mapped in 1936 and shown in table A of Part III was 115,705 acres. Breaking this down to the classifications indicated, and applying the Bureau of Agricultural Engineering estimates of unit consumptive use as given in table 76 less 0.6 foot for precipitation, gives a total stream-flow depletion for this area of 117,000 acre-feet. This is substantially lower than the mean annual depletion as given by the stream-flow records. In selecting the depletion figure to be used in deriving the diversion demand for this area, it was considered inadvisable to depart materially from the mean of actual depletions in recent years. A round figure of 150,000 acre-feet was therefore adopted. In the section of this report on return water, table 39 shows a return in 1936 for the Conejos area amounting to 44 percent of the diversions. This high percentage is ascribed to the present conditions of wild flooding which prevail in the Conejos area during the short period of spring run-off when heavy overdiversions are made in an endeavor to offset to some degree the effects of the extreme lack of conformity between the irrigation demand and the unregulated supply. With a supply regulated by storage, overdiversion should be eliminated to great extent with a corresponding reduction in the return water percentage. In view of these considerations, a figure of 35 percent was adopted as representing the proportion of the diversions which would be returned as indivertible waste and drainage. Using this percentage, the diversion demand on the Conejos River for the Conejos area becomes 230,000 acre-feet. It is necessary to divide this demand into that for the area above, and that for the area below, the junction of the San Antonio with the Conejos, in order that the amount of usable and indivertible inflow of the San Antonio may be determined. The 1936 survey shows that 88 percent of the area mapped lies below the junction. Using this as a basis of division, the Conejos River diversion demand is 30,000 acre-feet above and 200,000 acre-feet below the junction.

For monthly distribution of the demand the same ideal distribution was used as in the case of diversions from Rio Grande. Likewise, the same monthly distribution was assigned to the return flow as in the case of return from Rio Grande diversions. The distributions of the demand and return flow are shown in table 84.

The Middle section.—The demand on Rio Grande at Otowi Bridge for the area from that point to San Marcial, including the area of the Middle Rio Grande Conservancy District, was derived by selection of a value for the stream-flow depletion between Otowi Bridge and San Marcial based on consideration of four separate estimates of that depletion.

Stream Flow Depletion, 1890–1935.—In the section of this report on water supply, in connection with the correction of recorded Rio Grande run-off for present development, estimates were derived for mean annual stream-flow depletion and tributary inflow, 1890–1935, Otowi Bridge to San Marcial, of 586,000 and 359,000 acre-feet, respectively. Comment was made that because of the uncertainty with respect to tributary inflow, nothing better than rough approximations of these quantities is possible and that the figures derived should be considered accordingly.

Stream-flow Depletion Based on Water Production Estimates.—In the estimates of water production, Appendix B of this report, table 199 gives the estimated annual water production 1890 to 1935 of the southern unit of the Middle section. This is the unit of the Rio Grande drainage area from Otowi Bridge to San Marcial. The production figures represent the natural run-off of tributary streams above irrigation depletions. The latter can be estimated from the data on irrigated areas and consumptive use as given in table B, Part III, and table 78, respectively. If the depletions so derived are then deducted from the water production figures an approximation of the Rio Grande tributary inflow, Otowi Bridge to San Marcial, may be obtained which is entirely independent of any other derivations of this tributary inflow as given in this report. The sum of the tributary inflow and the difference in flow between Otowi Bridge and San Marcial then affords an independent estimate of the Middle Valley depletion. The derivation of such an estimate is indicated in table 85. Table B shows a total water-consuming area in the tributary valleys of 40,000 acres. Unit depletion figures based on the data of table 78 were applied to the acreages of the various classes comprised in the 40,000 acres giving a total depletion of 63,000 acre-feet. This represents an average unit stream-flow depletion of 1.6 acre-feet per acre, or a consumptive use of 2.6 acre-feet per acre (1.0 foot was allowed for precipitation). The

63,000 acre-feet was taken as the depletion for years of normal or greater run-off and reduced for less than normal years, roughly in proportion to the percentage below normal of the southern unit run-off as given by table 199.

[illegible] *1890–1935, based on tributary inflow derived from water production estimates*

[illegible]

[illegible]	Water pro- [illegible] gation	[illegible] in tributary valleys	[illegible] tributary inflow (2)−(3)	[illegible]	[illegible]
	(2)	(3)	[illegible]		
[illegible]	[illegible]	[illegible]	547	[illegible]	[illegible]
[illegible]	818	[illegible]	[illegible]	−292	[illegible]
[illegible]	[illegible]	63	537	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	207	[illegible]	[illegible]
[illegible]	[illegible]	15	105	146	251
[illegible]	[illegible]	63	377	37	414
1896	125	16	109	121	250
[illegible]	710	[illegible]	[illegible]	−320	[illegible]
[illegible]	185	40	145	127	272
[illegible]	148	27	121	442	[illegible]
[illegible]	102	[illegible]	95	240	335
[illegible]	188	40	148	[illegible]	348
[illegible]	[illegible]	[illegible]	[illegible]	223	291
[illegible]	[illegible]	[illegible]	539	397	936
[illegible]	168	34	134	[illegible]	152
[illegible]	[illegible]	[illegible]	557	−373	184
[illegible]	[illegible]	63	567	353	920
[illegible]	[illegible]	[illegible]	792	594	1,386
[illegible]	[illegible]	54	216	247	[illegible]
[illegible]	[illegible]	[illegible]	197	655	1,152
1910	[illegible]	[illegible]	258	416	654
[illegible]	625	[illegible]	[illegible]	[illegible]	870
[illegible]	[illegible]	[illegible]	555	409	[illegible]
1913	171	[illegible]	137	246	383
[illegible]	447	63	[illegible]	317	701
[illegible]	[illegible]	63	696	293	989
1916	[illegible]	63	[illegible]	377	[illegible]
[illegible]	[illegible]	42	[illegible]	382	540
1918	[illegible]	30	126	[illegible]	[illegible]
1919	[illegible]	[illegible]	[illegible]	87	[illegible]
[illegible]	[illegible]	62	[illegible]	136	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	118	[illegible]
1922	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	40	[illegible]	[illegible]	[illegible]
[illegible]	309	57	[illegible]	213	[illegible]
[illegible]	168	[illegible]	134	[illegible]	[illegible]
[illegible]	514	[illegible]	451	268	719
[illegible]	[illegible]	63	529	[illegible]	811
1928	167	[illegible]	[illegible]	[illegible]	[illegible]
1929	407	63	344	[illegible]	[illegible]
1930	[illegible]	49	[illegible]	191	[illegible]
1931	113	13	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	63	[illegible]	[illegible]	[illegible]
1933	207	44	[illegible]	65	[illegible]
[illegible]	[illegible]	40	[illegible]	[illegible]	283
1935	[illegible]	63	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The mean annual values for Middle Valley depletion and tributary inflow given by this estimate are 562,000 and 337,000 acre-feet, respectively.

Stream-Flow Depletion in 1936.—Subsequent to the studies which gave the figures of the preceding paragraphs the 1936 records of Middle Valley stream flow, diversions, and drainage, as obtained under the Rio Grande joint investigation, became available, and an analysis of these data was made in an endeavor to determine the stream-flow depletion and tributary inflow in 1936. The measurements gave a record of all surface flow in river, canals, and drains past seven cross sections of the valley: Otowi Bridge, Cochiti, San Felipe, Isleta, Bernardo, San Acacia, and San Marcial. It was thought that with these records and those of the diversions and drain flow in each of the six river sections, the stream-flow depletion and tributary inflow might be isolated for each section and finally summed up to give the valley totals. This was found to be impractical, however, because of lack of sufficient data on wastes. There are a great many wasteways in the conservancy district below the points where the diversions to the canals are measured and it was only possible to measure a small portion of these wastes in 1936. Hence, data on net diversions, an essential item, were not available. Lacking the data for this determination, attention was directed to utilization of the available data to furnish an estimate of minimum tributary inflow, from which the minimum stream-flow depletion might be derived. The daily records of total inflow and outflow for the six river sections from Otowi Bridge to San Marcial were compared, making due allowance for time lag between cross sections, to give the gains in each section. Only days when gains were indicated were tabulated. From the indicated gain between upper and lower limits of a section, the outflow of interior drains, considered as having no source in tributary inflow, was subtracted (a correction which would probably be strictly applicable only to winter months when there are no diversions), and to the gain was added the estimated evaporation from the river surface in the section. Manifestly, if there is a gain in a section it represents the excess of tributary inflow over that portion which supplies the total consumption in the section. Hence the gains in the section as above derived less drain flow and plus only that part of the consumption in the section represented by the evaporation from the river surface must of necessity account for the very minimum of tributary inflow. Consideration was given to the available records of flow of Jemez Creek at its mouth, but not to those of Rio Puerco at Rio Puerco, as the latter station is about 25 miles above the mouth and there are undoubtedly substantial losses below the station. If the tributary inflow as derived for the San Felipe-Isleta section was smaller than the flow of Jemez Creek, the recorded flow of the latter was taken as the total tributary inflow. This is conservative as there were, in all probability, other concurrent sources of tributary inflow to the section. The deductions of daily tributary inflow were summed up by months for each section as shown in table 86. Complete records for the year were not available for each section, so that, as indicated, combinations of longer sections were necessary for some months to complete the estimates. As shown by this table the total of the estimated minimum tributary inflow to the Middle Valley in 1936 is 362,000 acre-feet. The monthly totals of table 86

TABLE 86.—*Estimated minimum tributary inflow, Middle Rio Grande Valley, Otowi Bridge to San Marcial, 1936*

[Unit, 1,000 acre-feet]

River section	January	February	March	April	May	June	July	August	September	October	November	December	Year
Otowi Bridge to Cochiti	2.0	8.0	6.6	8.7	8.4	0.6	1.5	0.9	0.8	0.5	1.6	1.3	40.9
Cochiti to San Felipe	4.3	2.5	7.5	30.1	17.5	9.0	8.6	7.4	3.6	3.6	1.5	.8	96.4
San Felipe to Isleta	..					[1] 0	8.0	3.3	25.4	6.5	8.2	6.7	58.1
Isleta to Bernardo						[1] .2	0	0	0	0	0	0	.2
Bernardo to San Acacia						[1] 2.2	5.1	26.3	20.0	8.2	3.3	4.6	69.7
San Acacia to San Marcial				[2] 20.1	3.1	0	0	1.5	1.6	0	0	0	26.3
San Felipe to San Acacia				[2] 20.1	25.0	[3] 0.9							46.0
San Felipe to San Marcial	5.6	.9	0	[4] 17.5									24.0
Total	11.9	11.4	14.1	96.5	54.0	12.9	23.2	39.4	51.4	18.8	14.6	13.4	361.6

[1] June 14-30. [2] Apr. 18-30. [3] June 1-13. [4] Apr. 1-17.

applied to the monthly differences between Otowi Bridge and San Marcial gave monthly figures for minimum stream-flow depletion as shown in table 87. These total 566,000 acre-feet for the year as the estimated minimum stream-flow depletion in the Middle Valley in 1936.

TABLE 87.—*Estimated minimum stream flow depletion, Middle Rio Grande Valley, Otowi Bridge to San Marcial, 1936*

[Unit, 1,000 acre-feet]

Month	Otowi Bridge inflow less San Marcial outflow	Estimated minimum tributary inflow	Corresponding minimum stream flow depletion
January	−17.4	11.9	−5.5
February	−6.8	11.4	4.6
March	−.9	14.1	13.2
April	45.8	96.5	142.3
May	22.1	54.0	76.1
June	59.4	12.9	72.3
July	38.8	23.2	62.0
August	38.2	39.4	77.6
September	1.7	51.4	53.1
October	12.6	18.8	31.4
November	14.4	14.6	29.0
December	−3.2	13.4	10.2
Year	204.7	361.6	566.3

Stream-flow Depletion by Integration Method.—As shown in table 79, the Bureau of Agricultural Engineering has applied unit values for consumption, determined on the basis of all available data, to the mapped areas to derive the total consumptive water requirement on the main stem of Rio Grande from the Colorado State line to San Marcial. Deducting from the total the consumption shown for the area above Otowi Bridge (Buckman) gives a consumption of 675,000 acre-feet from Otowi Bridge to San Marcial. (This does not include the canyon section from Otowi Bridge to Cochiti, which was not mapped.) Allowing 0.7 foot for precipitation on the total area of 205,000 acres gives a deduction of 144,000 acre-feet to make the estimated stream-flow depletion, Otowi Bridge to San Marcial, 531,000 acre-feet.

Diversion Demand on Rio Grande.—Four estimates of stream-flow depletion, Otowi Bridge to San Marcial, have been described: (1) 586,000 acre-feet based on a study of available data for the period 1890–1935, (2) 562,000 acre-feet based on tributary inflow derived from water-production estimates, (3) 566,000 acre-feet as a minimum based on 1936 data, and (4) 531,000 acre-feet based on unit-consumption values derived from experience and judgment applied to the mapped acreage. Estimates by previous investigators are shown by table 73 to have been substantially lower, in most cases, than any of these four. Since, in any case the deficiency in basic data has been such that approximations only were possible, a depletion figure of 550,000 acre-feet was more or less arbitrarily fixed upon as the basis in this report for deriving the required diversion demand upon the Rio Grande of the Middle Valley area.

As indicated by table 71, the irrigated area in the Middle Rio Grande Conservancy District in 1936 was 59,000 acres. The Burkholder report (table 5, p. 3) shows that the net irrigable area included in the district as set forth in the approved plan, is 123,267 acres. Assuming that under full development the maximum acreage irrigated in any one year would be 80 percent of this, or, in round numbers, 100,000 acres, the question of whether an allowance should be made for greater stream-flow depletion when the 100,000 acres are irrigated is to be considered.

Reference to the figures for the conservancy district in table B, Part III, shows that there were in the district in 1936, 43,968 acres in grass and 19,639 acres in brush. If the irrigated lands are not expanded to include bosque areas (which show a higher rate of water consumption than grass or brush lands) it appears that the grass and brush lands must be those which will later be brought under cultivation and irrigated in making up the 100,000 acres. By applying the unit consumptive use figures given in table 78 for grass and brush in the conservancy district to their respective acreages as given above, a total consumption of 169,000 acre-feet is obtained. This divided by the total acreage of grass and brush lands gives an average unit consumptive use for them of 2.66 acre-feet per acre. A similar computation for the irrigated lands in the district, using the data of table 79, gives 2.66 acre-feet per acre, or precisely the

[illegible] for these lands as for the grass and brush lands.

From the above considerations it appears that no increase over present consumption or stream-flow depletion is to be anticipated with the future increase in the irrigated acreage of the Middle Rio Grande Conservancy District. No allowance was made, therefore, for a future average annual stream-flow depletion, Otowi Bridge to San Marcial, greater than 550,000 acre-feet.

Of the 550,000 acre-feet depletion, the consumption figures of table 79 for the area between the Middle Rio Grande Conservancy District and San Marcial indicate that stream-flow depletion of about 80,000 acre-feet occurs in this area. Since this is depletion caused principally by swamp, bosque, and pooled water surfaces, it need not be supplied on an irrigation schedule and can be assumed to draw upon indivertible drainage return, wastes, and tributary inflow.

To derive the diversion demand, indivertible return and wastes were added to the depletion figure and the dependable contribution of divertible tributary inflow subtracted from it. Indivertible return was taken as the flow of interior drains from the Socorro division throughout the year and from the other divisions of the conservancy district in the months November to February, inclusive. From table 43, this totaled 70,000 acre-feet in 1936. Indivertible wastes were taken as those from the Socorro division only. Sluicing wastes, considered to be required only during 3 months of low river flow, were estimated from 1936 data at 20,000 acre-feet. Operation wastes were estimated at about a third of the gross diversions to Socorro division in 1936, or 20,000 acre-feet. Although two studies previously described give values for the total mean annual tributary inflow to Middle Valley of about 360,000 acre-feet, only a portion of this inflow is, of course, to be relied upon as a dependable and divertible source of supply. As conservatively representing that portion, the inflow from Otowi Bridge to San Felipe plus half only of Jemez Creek inflow (because of its confluence with Rio Grande below important diversion points and occasional indivertible peaks) was adopted. From the data of table 86 and that of Jemez Creek discharge, this portion of the valley's total tributary inflow in 1936 amounted to about 150,000 acre-feet, or slightly over 40 percent of the total. In order to allow for the divertible tributary inflow in determining the diversion demand in past years, monthly percentages based on the ratio of the Otowi Bridge-San Felipe-Half Jemez inflow to the total, as given by 1936 data, were computed and applied to the monthly estimates of total inflow in past years given by table 23. The percentages so used, reduced slightly from the computed values and rounded, are shown in table 88. In the operation studies described in a subsequent section, it was found that the mean, 1911–35, of usable tributary inflow derived by application of the percentages as above described was 110,000 acre-feet, or 31 percent of the mean, for the same period of the total tributary inflow. In deriving the monthly distribution of the diversion demand, that on the irrigation schedule was based on 1936 diversions of the conservancy district and the original distribution figures as proposed in the Burkholder report of that district. The demand for the area of native vegetation and water surfaces below the district was distributed in accordance with net monthly evaporation from Elephant Butte Reservoir. Monthly distribution of return flow was based on 1936

TABLE 88.—*Middle Valley diversion demand on Rio Grande, Otowi Bridge to San Marcial*

[illegible]

Month	[illegible] Middle Rio Grande Conservancy District [illegible]: [illegible]	[illegible]	[illegible] Socorro division	Total demand	[illegible] for tributary inflow ([illegible] tributary inflow)	Demand	[illegible]: Operation [illegible]	[illegible]: Sluicing waste	[illegible]: [illegible] return	Net return or [illegible]
(1)	(2)	[illegible]	(4)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0	0	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	3	17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	−3
April	15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	−6
June	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
December	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

Column 11 (8)+(9)+(10)−(7). Negatives can be supplied from river surplus or indivertible tributary inflow, not necessarily during current month, but during season.

records for interior drains. The monthly distributions and totals of the quantities thus determined as those to be used to give the net diversion demand on Rio Grande for the Middle Valley are shown in table 88.

The Elephant Butte-Fort Quitman Section. Derivation of the demand upon Rio Grande at San Marcial, or upon Elephant Butte Reservoir, for the area of the Elephant Butte-Fort Quitman section was based on the actual diversions and use of water in the section from 1930 to 1936, inclusive, as shown by a detailed study of river flow, net diversions, drainage, river-bed losses, and arroyo inflow in four river sections from Elephant Butte Dam to Fort Quitman. Certain modifications of the requirements indicated by the data of this period were made to allow for salinity control, the economy to be effected upon completion of the American diversion dam, and the irrigated acreage for complete development of Rio Grande Project. The diversion demand was also derived independently, by use of the consumptive requirement data of the Bureau of Agricultural Engineering.

Net Diversions and Stream-flow Depletion, 1930–36.—In a study to derive monthly stream-flow depletion as well as to account as nearly as possible for all losses and gains in the Elephant Butte-Fort Quitman section in the period 1930 to 1936, the section was divided into four divisions—Elephant Butte-Leasburg, Leasburg-El Paso, El Paso-Tornillo, and Tornillo-Fort Quitman. Records were available as follows: River flow at upper and lower limits of divisions, full period; canal diversions, wastes, and drain flow for each of the three upper divisions, and to the lower boundary of Rio Grande Project in the lowest division, full period; diversions to Hudspeth district, main canal, full period, and Alamo feeder, 1931–36; Hudspeth drainage and waste, 1936 only. No records were available of Mexican diversions, waste, or drainage. Estimates of arroyo inflow were used as derived in Appendix B of this report. In the El Paso-Tornillo division it was estimated as one-third, and in the Tornillo-Fort Quitman division as two-thirds of the total inflow from El Paso to Fort Quitman. In the two upper divisions the differences between river inflow and outflow, after correction for intervening arroyo inflow, diversions, wastes to river, and drainage return, were attributed to river-bed loss or gain. In the El Paso-Tornillo division, river-bed losses were assumed as half the 7-year mean of river-bed losses in the Leasburg-El Paso division. This, then, gave Mexican diversions in this division as the residual after correcting the inflow-outflow differences for arroyo inflow, net diversions, drainage return, and river-bed losses. Completion of the analysis for the Tornillo-Fort Quitman division required that the Hudspeth drainage and wastes 1930 to 1935 be estimated on the basis of the 1936 data. An assumption of relatively high river-bed losses at approximately one-fourth of the Rio Grande flow below the Rio Grande Project gave Mexican diversions in this division as residuals of the analysis which are probably conservative.

In addition to the analyses above described, an accompanying study was made to determine the disposition of Elephant Butte Reservoir releases by estimating the respective amounts of unused (first use water from the reservoir as distinguished from returned drainage originally from the reservoir) reservoir releases, arroyo inflow, and drainage return included in the net diversions and river losses, and in the river flow passing the lower station of each division. This necessitated certain assumptions with respect to the effective

TABLE 89.—*Estimated net Rio Grande Diversions by Mexico, Juarez to Fort Quitman, 1930–36* [1]

[Unit, acre-feet]

Month	1930	1931	1932	1933	1934	1935	1936	Mean	Specified by Mexican treaty
JUAREZ TO TORNILLO BRIDGE [2]									
January	2,100	4,500	4,600	4,700	4,600	1,500	2,000	3,500	0
February	600	3,500	1,500	7,100	3,200	2,700	2,800	3,100	1,090
March	2,000	7,000	9,500	12,500	3,400	6,100	4,600	6,500	5,460
April	8,200	6,800	13,800	11,900	11,800	16,700	11,200	11,500	12,000
May	12,500	7,500	16,200	13,500	17,200	18,400	20,100	15,000	12,000
June	13,500	13,600	20,600	16,700	20,100	21,900	16,200	17,500	12,000
July	17,900	17,900	22,500	18,900	21,800	27,100	18,200	20,700	8,180
August	14,800	15,500	24,900	24,800	28,400	10,000	20,900	24,300	4,370
September	12,300	11,900	19,400	12,300	8,500	9,500	6,300	11,400	3,270
October	8,200	11,800	3,500	10,200	6,900	5,000	4,200	7,000	1,090
November	6,200	6,400	9,600	10,600	5,200	1,400	1,700	5,900	540
December	4,600	5,500	7,400	8,900	4,500	1,000	100	4,500	0
Year	102,900	111,900	153,700	152,100	135,600	151,300	108,300	130,900	60,000
TORNILLO BRIDGE TO FORT QUITMAN									
Year	41,000	50,000	65,000	45,000	57,000	28,000	35,000	46,000	

[1] Estimates derived as residuals after accounting for all other losses and gains in river section. In accordance with probable accuracy and extent of necessary assumptions, estimates for upper section are considered reasonably good; those for lower section only fair.
[2] Includes Guadalupe Canal waste to Mexico.

TABLE 90.—*Estimated percentages of reservoir water, arroyo inflow, and drainage in net diversions and disposal of reservoir* [illegible]

[illegible]	[illegible] distribu- [illegible]	[illegible] reservoir [illegible]	[illegible] inflow	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	2.2	[illegible]	[illegible]
[illegible]	[illegible]	89.8	2.8	7.4	100.0
[illegible]	18.4	58.4			
[illegible]		[illegible]	3.4	35.1	100.0
[illegible]		38.2	4.1	57.7	100.0
[illegible]	73.3	79.8	3.0	17.2	[illegible]
[illegible]	...	33.9	[illegible]	60.0	[illegible]
Juarez (Mexico)	11.4	[illegible]	[illegible]	45.1	100.0
[illegible]		58.3	3.1	38.6	100.0
[illegible]		24.4	11.8	[illegible]	100.0
[illegible]	9.2				
[illegible]	[illegible]	17.2	14.8	[illegible]	[illegible]
[illegible]	100.0				

[1] [illegible]
[2] Invisible accretion to river.

[illegible] voir releases, diversions, wastes, drain flow, and arroyo inflow

TABLE 91.—*Average net diversions and stream-flow depletion in divisions of Elephant Butte-Fort Quitman section, 1930 to 1936, inclusive*

[illegible]

[illegible]	[illegible]	Drainage return	Stream-flow depletion [1]
[illegible]	[illegible]	35.0	32.0
[illegible]	[illegible]	192.9	201.9
[illegible]	[2] 212.1	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		
[illegible]	46		

[1] Note that from nature of derivation (net diversions less drainage) these stream- [illegible]
[2] [illegible]
[3] [illegible]
[4] [illegible]
[5] [illegible]

amounts of arroyo inflow and drainage return in each division and these were made to conform as closely as possible with actual physical limitations and known operation practices.

Summaries of the data derived by these studies are given in tables 89 to 92. Table 89 shows the estimated net diversions by Mexico and indicates a mean annual diversion, 1930 to 1936, between Juarez and Tornillo Bridge, of 71,000 acre-feet in excess of the treaty allotment. In addition, Mexican diversions between Tornillo Bridge and Fort Quitman are roughly estimated at close to 50,000 acre-feet, making a total diversion of about three times the treaty allotment. There are probably no diversions in January as table 89 would indicate. However, since the diversions were derived as residual quantities, the mean amount shown for January of 3,500 acre-feet, or less than 3 percent of the mean annual diversion, is well within the limit of error to be anticipated under this method of analysis.

Table 90 shows the estimated percentages of unused reservoir water, arroyo inflow, and drain flow in the net diversions to the various divisions and in the flow passing Fort Quitman; also the mean percentage of total reservoir releases distributed to each division. It is indicated that the water to lower El Paso division (Tornillo Canal) is only 38 percent unused reservoir water, while that to upper El Paso division (Franklin Canal) is 62 percent. Of the total reservoir releases the Rio Grande Project is shown as receiving 73 percent.

Tables 91 and 92 give the data on net diversions and stream-flow depletion. For the Rio Grande Project the mean annual depletion, 1930–36, is indicated to have been 351,000 acre-feet, or 2.58 acre-feet per acre irrigated. It is to be noted that from the

TABLE 92.—*Stream-flow depletion and acreage irrigated, Rio Grande Project, by divisions, 1930–36*

Item	1930	[illegible]	1932	[illegible]	1934	[illegible]	[illegible]	[illegible]
				[illegible]				
[illegible]	32,500	27,300	34,700	28,400	41,800	24,500	34,500	32,000
[illegible]	12,702	13,069	12,463	12,283	[illegible]	11,834	13,528	12,655
[illegible]	2.55	2.09	2.78	2.31	3.27	2.07	2.55	2.53
				[illegible]				
[illegible]	240,300	214,200	245,100	210,900	[illegible]	131,600	183,600	[illegible]
[illegible]	76,373	76,722	76,709	77,061	68,605	62,175	74,913	73,708
[illegible]	[illegible]	2.79	3.20	2.74	[illegible]	[illegible]	[illegible]	[illegible]
				[illegible]				
Stream-flow depletion, acre-feet	[illegible]	[illegible]	106,600	106,200	132,500	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	48,277	[illegible]	47,711	[illegible]	[illegible]	50,344
[illegible]	2.44	1.94	2.21	2.13	2.78	[illegible]	[illegible]	2.27
				[illegible]				
[illegible]	[illegible]	[illegible]	386,400	[illegible]	[illegible]	215,400	[illegible]	351,300
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	120,075	138,901	136,217
Depletion, acre-feet per acre	[illegible]	[illegible]	[illegible]	[illegible]	2.97	[illegible]	2.47	[illegible]

Acreage data as furnished by Bureau of Reclamation.
[illegible]

nature of the derivation of this stream-flow depletion (net diversions less drain flow) it does not include river-bed losses. Mean unit depletion figures shown for the three Project divisions are: Rincon, 2.53; Mesilla, 2.80; and El Paso, 2.27 acre-feet per irrigated acre.

Diversion Demand. The demand upon Elephant Butte Reservoir to be assured for the Elephant Butte-Fort Quitman section was considered to be that required by Rio Grande Project and fulfillment of the Mexican treaty obligation under the conditions which will prevail upon completion of the American diversion dam and extension to it of Franklin Canal, a project now under construction. By this development the 60,000 acre-feet required to be delivered to the Mexican Canal will be released to the river below the new dam so that it may be diverted as at present by the international dam. All other river water (except local flood waters) will be diverted to Franklin Canal by the American dam and carried to a point below the international dam where the water for Riverside, Hansen, and Tornillo Canal headings will be spilled back to the river. Under this arrangement the Mexican diversion at the international dam will be definitely limited to 60,000 acre-feet, and, assuming that the estimates of diversions by Mexico in the past as given in table 89 are reasonably correct, this means an average annual saving of about 70,000 acre-feet. In the section from Juarez to Tornillo Bridge there is another Mexican canal, San Augustine, which heads above the Hansen and Tornillo headings and which will, therefore, still be in a position to divert from the river. It is a small canal, however, compared to the Acequia Madre at the international dam. The present opportunity for diversions by other Mexican canals at lower river points will not be changed, but any diversions below Tornillo heading are from wastes and return waters. As the new arrangement makes no change in the delivery of water to Tornillo heading via the river channel into which drainage is discharged above the heading, no change in the quality of the water diverted at this heading is to be anticipated.

Assuming continued use of arroyo inflow and drainage return as in the 7-year period, 1930–36, the net diversion of reservoir water to be assured the Rio Grande project, taking the mean of 7 years of past diversions as a criterion, is given by the data of tables 90 and 91 as follows:

Mean net diversions of unused reservoir water, 1930–36

	Acre-feet
Rincon division	65, 300
Mesilla division	357, 400
El Paso division	141, 400
Rio Grande Project	564, 100

This was the net diversion for an average irrigated area on the project in the 7 years of 136,000 acres. The range in acreage irrigated in that 7-year period, as shown by table 92, was from a minimum of 120,000 in 1935 to a maximum of 145,000 in 1930. The figure for 1936 of 139,000 is close to the 7-year mean. Data obtained from the Bureau of Reclamation show a variation from year to year in the figure given for net irrigable area of the Project. The variation is small and is largely due to progress below El Paso in the river channel rectification program of the International Boundary Commission and consequent changes in sovereignty of lands exchanged between Mexico and the United States to maintain the international boundary in the center of the rectified channel. Taking a round figure of 175,000 acres, which is close to the average of the figures reported for the 11-year period 1926–36, the maximum irrigated acreage of 1930 was 83 percent and the minimum of 1935, 69 percent, of the net irrigable acreage. Experience has demonstrated that the acreage irrigated in any one year on a fully developed irrigation project rarely exceeds 90 percent of the irrigable area and generally ranges from less than 80 up to 90 percent. For the Rio Grande project it was considered that the maximum irrigated area of 145,000 acres could be taken as representing the irrigated acreage under full development. A comparison of annual reservoir releases 1930 to 1936 with the irrigated acreage of the project in the same years would seem to indicate that increase or decrease in the amounts of water released has had little or no relation to the changes from year to year in the irrigated acreage. Apparently the releases have been strongly influenced by other factors, such as arroyo inflow, precipitation, nature of crops, and impending water shortage. However, in order to assure an adequate diversion demand for an irrigated acreage of 145,000, the previous figure of 564,000 acre-feet for net diversion of unused reservoir water was increased by the ratio of 145,000 to 136,000, giving 600,000 acre-feet. This neglects the fact that any increase in the irrigated acreage over the mean of the past few years would, as shown by the 1936 survey and report of the Bureau of Agricultural Engineering, probably constitute a substitution of present water-consuming areas of native vegetation and hence involve no material increase in consumption.

An addition of 65,000 acre-feet to the net diversion requirement to allow for operation and other wastes indivertible by the project was derived as shown in table 93.

River-bed losses above Tornillo Heading of unused reservoir releases, another addition required, were derived for each division as the residual quantities after the reservoir water in net diversions was sub-

tracted from the differences between the amounts of reservoir water passing at upper and lower river stations of the division. The mean losses, 1930–36, so derived were 30,200 acre-feet in Rincon division, 26,800 in Mesilla division, and 6,500 in El Paso division down to Tornillo Heading, making a total of 63,500 acre-feet.

Using the figure of 61.5 percent shown in table 90 for the percentage of unused reservoir releases in the river water at El Paso, the release of reservoir water required to supply the treaty allotment of 60,000 acre-feet to Mexico becomes 37,000 acre-feet. The remainder is made up from drainage return and arroyo inflow.

The items making up the required diversion demand on Elephant Butte Reservoir, as developed in the discussion to this point, are:

	Acre-feet
Net diversions for Rio Grande project irrigated acreage of [illegible]	600, 000
Rio Grande project wastes	65, 000
River-bed losses above Tornillo Heading	64, 000
Fulfillment of Mexican treaty obligation	37, 000
Total	766, 000

TABLE 93.—*Derivation of operation and other wastes indivertible by Rio Grande Project*

Item	Project wastes		
	Total acre-feet	Percentage of unused reservoir water included [1]	Reservoir water (acre-feet)
[illegible]	[illegible]	[illegible]	32, 200
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	84, 100	38. 2	32, 100
Total	[illegible]		[illegible]

[illegible]

[2] Less than percentage for Tornillo canal because of indivertible arroyo inflow in- [illegible]

Additional Requirement for Salinity Control—As presented in a previous section of this report, investigation of the quality of water in the Upper Rio Grande Basin has shown increased concentrations of salt in the irrigation and drainage water in the downstream direction such that, whereas the average concentration of the irrigation water at El Paso at the head of Franklin canal, as shown by electrical conductance, is 127; the concentration at the head of Tornillo canal in the lower El Paso Valley is 212. The marked increase between these two points is of course due to the heavy depletion of Rio Grande flow in the vicinity of El Paso and the influx of drainage to the river just above Tornillo Heading. The percentages of unused reservoir releases in the river at the head of Franklin and Tornillo canals, as shown by table 90, are respectively 62 and 38, and it is to be noted that the ratio of these percentages is almost exactly equal to the inverse ratio of the average conductances of the water at the two points.

The water users of the lower El Paso Valley have complained of damage to crops and have attributed it to high salt concentrations in the irrigation water, particularly in such a year as 1935, when, following the dry year of 1934 and resultant low level in Elephant Butte Reservoir, diversions and waste were definitely reduced in fear of an impending shortage. Table 94 gives the net diversions and acreage irrigated in upper El Paso Valley under Franklin and Riverside canals and in the lower valley under Tornillo canal for the years 1934, 1935, and 1936. Data on the irrigated acreage under Tornillo canal for earlier years were not available. This table shows the reduction made in 1935 in the diversion per acre in both upper and lower sections of the valley. It shows also that there has apparently been no greater unit application of water made under Tornillo canal for the purpose of minimizing the effects of higher salt concentrations than in upper El Paso Valley.

TABLE 94.—*Comparison of net diversions per irrigated acre under upper and lower El Paso Valley canals of Rio Grande Project, 1934–36*

Item	1934	1935	1936	Mean
UPPER EL PASO VALLEY—FRANKLIN AND RIVERSIDE CANALS				
Acreage irrigated	40, 819	[illegible]	42, 776	41, 157
Net diversions—total acre-feet	226, 800	[illegible]	202, 000	[illegible]
Acre-feet per irrigated acre	[illegible]	4. 38	[illegible]	[illegible]
LOWER EL PASO VALLEY—TORNILLO CANAL				
Acreage irrigated	6, 892	6, 191	[illegible]	6, 922
Net diversions—total acre-feet	[illegible]	[illegible]	35, 400	32, 700
Acre-feet per irrigated acre	[illegible]	3. 89	[illegible]	4. 72

In accordance with the data and discussion of quality of water in a previous section of this report, high salt concentrations in the irrigation water must be offset by greater applications of water to the land, if the concentration of the soil solution in the root zone of the plants is to be maintained low enough so that the plants will not suffer. With respect to such control it was stated that the indefiniteness under present knowledge of the quantitative factors involved lead in this report to more or less arbitrary assumptions as to the amount of additional water needed to be applied to maintain a satisfactory salt balance. Furthermore, after due consideration of the available information regarding adverse salinity conditions in the valley

below El Paso, it was determined to assume the need for such additional water only in the area of the Rio Grande Project that lies under Tornillo canal.

It is indicated that the average salt concentration of the water available for diversion at the Franklin and Riverside headings is within the range of permissible amounts. At the Tornillo Heading, however, concentrations are claimed to be high enough to show injurious effects on vegetation. Hence, although, as indicated by table 94, no increase in the Tornillo diversions per acre over those of Franklin and Riverside has been made, it appears that some increase should be made.

With respect to the magnitude of the increase to be made, it seemed best to arbitrarily assume an amount which could be considered reasonable, pending the collecting of data over a number of years to determine definitely its adequacy. The increase in diversions thus assumed for the Tornillo canal was 60 percent.

From table 91 the mean net diversion, 1930–36, by Tornillo canal was 31,400 acre-feet. An increase of 60 percent amounts to 18,800 acre-feet, making a total diversion of 50,200 acre-feet, which is 3.2 times the estimated average stream-flow depletion in the Tornillo unit. This is to be compared with an average net diversion, 1930–36, to the entire El Paso division of 2.1 times the stream-flow depletion therein, as indicated by table 91.

In considering this allowance for salinity control, cognizance should be taken of the liberal allowance which was made for wastes, as shown in table 93, in deriving the Rio Grande Project diversion demand.

Of the 18,800 acre-feet increase indicated for Tornillo canal, 38 percent, as taken from table 90, or 7,100 acre-feet, would be unused reservoir release. Taking, then, 7,000 acre-feet as a rounded figure for salinity control, its addition to the previous total derived for the annual demand upon Elephant Butte Reservoir gives 773,000 acre-feet. This is the demand adopted in this report for subsequent reservoir operation studies. The annual demand on Rio Grande at San Marcial was derived by adding the estimated mean annual amounts of evaporation and seepage from Elephant Butte Reservoir. From data and analyses given in the section of this report on water supply, mean annual seepage losses were estimated at 60,000 acre-feet and evaporation at 120,000 acre-feet. The latter represents the mean for the period 1915–35. A summarization of the items included in the total of the required demand on San Marcial is given in table 95.

Depletion and Diversion Demand by Integration Method.—Using the Bureau of Agricultural Engineering data on acreages and estimated consumptive requirements as given in table 81, and reducing unit values for consumption by 0.7 foot to correct for precipitation, the stream-flow depletion requirement for the Rio Grande Project area is derived as follows:

[illegible]	[illegible]	Stream-flow depletion	
		Unit, acre-feet per acre	[illegible] acre-feet
Irrigated area	[illegible]	2.1	[illegible]
Native vegetation	[illegible]	2.7	[illegible]
Miscellaneous	[illegible]	1.9	[illegible]
Total	211,170		[illegible]

TABLE 95.—*Required annual diversion demand upon Rio Grande at San Marcial for Rio Grande project and Mexican treaty obligation*

Item	Annual demand in acre-feet	
	Elephant Butte Reservoir	San Marcial
Net diversions for Rio Grande project irrigated acreage of [illegible]	600,000	
Rio Grande project waste	65,000	
Riverbed losses above Tornillo Heading	64,000	
Salinity control in area under Tornillo canal	7,000	
Fulfillment of Mexican Treaty obligation	37,000	
Total reservoir releases		773,000
Reservoir evaporation	120,000	
Reservoir seepage	60,000	
Total reservoir losses		180,000
Total demand on San Marcial		[illegible]

This total includes all losses in the area. To compare it with the Project figure of 351,000 acre-feet previously derived by subtracting drain return from net diversions, it must be reduced by the losses, such as those from the river bed, not included in the 351,000 acre-feet. The mean annual river-bed losses above Tornillo Heading as derived by the detail study of 1930–36 data was 90,000 acre-feet. Subtracting this from 457,000 gives 367,000 acre-feet for the Project stream-flow depletion by the integration method, as against the 351,000 acre-feet.

The necessary allowances for drain flow, wastes, arroyo inflow, and salinity control to derive the required diversion demand on Elephant Butte Reservoir, based on the total Project stream-flow depletion of 457,000 acre-feet, are indicated in the following summary:

		Acre-feet
Total required stream-flow depletion, Rio Grande Project, by integration method		457,000
Flow in river passing Tornillo Heading in 1936 [1]	117,400	
Total of arroyo inflow above Tornillo Heading, mean 1930–36	53,200	
Net river waste below project		64,200
Indivertible wastes and drain flow below project, comprising drain flow and waste discharging below Tornillo Bridge, waste to Mexico from Guadalupe Canal, Tornillo Canal waste, and Hudspeth diversion, mean 1930–36		136,000

[1] 1936 flow considered as probably more representative of future conditions than the 7-year mean because of marked reduction in flow beginning with 1934.

	Acre-feet
Salinity control in area under Tornillo Canal [2]	19,000
Fulfillment of Mexican Treaty obligation	60,000
Total required demand on Elephant Butte Reservoir	736,000

[illegible]

This demand on the reservoir of 736,000 acre-feet lacks 37,000 acre-feet of agreement with the corresponding demand of 773,000 acre-feet as derived in the previous analysis. If in the 773,000 acre-feet derivation, no increase had been made in the mean net diversion figure of 564,000 acre-feet in accordance with the ratio of 145,000 acres, as the irrigated acreage of complete development, to 136,000 acres, the 7-year mean of irrigated acreage, the resulting summation for the demand on the reservoir would have been 737,000 acre-feet; a demand practically identical with that derived by the integration method using the Bureau of Agricultural Engineering estimates of unit consumption. Notwithstanding the implication of the foregoing, and in view of the fact that between 144,000 and 145,000 acres were actually irrigated in 1929, 1930, and 1931, and more than 142,000 in 1926 and 1928, it was considered that the required demand on the reservoir of 773,000 acre-feet should be used as a conservative estimate.

Monthly Distribution of Demand on Reservoir.—The monthly distribution of the adopted demand on the reservoir was taken to correspond with the mean monthly distribution of total net diversions to Rio Grande Project in the period 1930 to 1936. Although this does not conform exactly to the distribution specified by the Mexican Treaty for delivery of the 60,000 acre-feet to Mexico, the latter represents a relatively small portion of the total demand on the reservoir so that any modification of the distribution as derived for the Project, to correct for it, was considered unnecessary. The adopted distribution is shown in table 96. The peculiar drop in May after the heavier draft of April is characteristic of diversions in the Rio Grande Project and occurs in most years in all three divisions.

TABLE 96.—*Monthly distribution of required annual demand on Elephant Butte Reservoir*

Month	Monthly distribution of demand [illegible]	
	Percentage	Acre-feet
January	[illegible]	[illegible]
February	[illegible]	[illegible]
March	[illegible]	[illegible]
April	[illegible]	[illegible]
May	[illegible]	[illegible]
June	[illegible]	[illegible]
July	[illegible]	[illegible]
August	16	[illegible]
September	[illegible]	70,000
October	[illegible]	15,000
November	1	8,000
December	[illegible]	[illegible]
Year	100	773,000

[illegible]

Uses and Requirements Other Than Those for Irrigation

The total use of water in the Upper Rio Grande Basin for purposes other than irrigation is but a small fraction of the irrigation use. Such other use is represented by domestic consumption in cities, towns, and villages as the principal, and power generation as a very minor, use. Construction which will increase the power use is now under way. As another classification, plans have been made by the Biological Survey for use of water for a large migratory waterfowl refuge on the Bosque del Apache Grant north of San Marcial.

Use by Cities, Towns, and Villages

As a general average it has been observed that the water requirement of cities and towns corresponds closely to the irrigation requirement of agricultural lands of equivalent area. Hence, in mapping and tabulating the irrigated and water-consuming areas of the Upper Rio Grande Basin, the Bureau of Agricultural Engineering included the area of cities, towns, and villages in a special classification as shown in table 71, and in deriving the consumptive requirements of the various units of the basin, as shown in tables 76 to 81, a unit consumption corresponding to agricultural use was selected and applied to the areas of this classification to give their total consumption. Except for surface supplies in a few instances in some of the tributary areas, the city, town, and village water supplies are practically all obtained by pumping from ground water which, in turn, has its source in stream flow and in precipitation on the floor of the valleys. From a basin-wide standpoint, therefore, this use constitutes a stream-flow depletion. By including the areas of cities, towns, and villages in the total areas for which consumptive requirements are estimated, the demands upon stream flow derived therefrom for the major units of the basin, as developed in preceding paragraphs of this section of the report, have included an allowance for city, town, and village use. Hence no special consideration of this use or allowance for it is here required.

Table 97 gives the area of the cities, towns, and villages and corresponding stream-flow depletion as derived from the Bureau of Agricultural Engineering data. Albuquerque is included in the figures for the Middle section, but El Paso is excluded from those for the Elephant Butte-Fort Quitman section. Exclusive of El Paso's use, this shows a total annual stream-flow

depletion by the cities, towns, and villages in the entire Upper Rio Grande Basin of 21,000 acre-feet.

While the supply for cities and towns is here treated as a consumptive use, it is to be observed that the sewage, whether raw, treated, or spread by broad irrigation, becomes return water as effectively as the return from irrigation. The aggregate amount probably varies between 60 and 75 percent of the city supply and is, therefore, relatively greater than return from irrigation.

In San Luis Valley the water supply of practically all towns and villages which overly the artesian basin is derived from artesian wells. The survey of artesian wells in the valley made by the Geological Survey in 1936 indicated a total of 1,380 artesian wells in Alamosa, Center, La Jara, Monte Vista, and Sanford, with a total annual discharge of about 8,700 acre-feet.

TABLE 97.—*Estimated water consumption by cities, towns, and villages in the Upper Rio Grande Basin*

Basin unit	Area of cities, towns, and villages (acres)	Annual stream-flow depletion	
		Unit, acre-feet per acre	Total acre-feet
(1)	(2)	(3)	(4)
San Luis section:			
Closed basin	1,034	0.9	930
Southwest area	4,103	.9	3,700
Southeast area	892	.9	800
Total	6,029		5,430
Middle section:			
Main stem Rio Grande from Colorado line to San Marcial	[1] 6,398	1.3	8,320
West side tributary areas	1,540	1.0	1,540
East side tributary areas	2,313	1.0	2,310
Total	10,251		12,170
Elephant Butte-Fort Quitman section: [2]			
San Marcial to Texas State line	1,846	1.3	2,400
El Paso to Fort Quitman in Texas	787	1.3	1,020
Total [2]	2,633		3,420
Total Upper Rio Grande Basin	18,913		21,000

[1] Includes Albuquerque.
[2] City of El Paso, 6,210 acres, is not included. The city and private industries are supplied from deep wells. Production of municipal wells in 1936 was 8,800 acre-feet. A 1936 survey of private and other than city wells made by the city water works indicated an annual production by these wells of about 5,600 acre-feet.

Column (2). From data of Bureau of Agricultural Engineering, table 71.
Column (3). From data of Bureau of Agricultural Engineering, tables 76, 78, and 80, corrected for precipitation.

The water supply for Albuquerque, a city of about 34,000 population, is obtained by deep-well pumping. The present annual draft on the wells is about 3,000 acre-feet, which represents an average daily consumption of 2.7 million gallons. The maximum daily consumption in summer months is about 6 million gallons. These figures correspond to an average consumption per capita per day of 80 gallons and a maximum of about 175 gallons. The city has filed an application with the Federal Emergency Administration of Public Works for a project which would substitute a mountain supply from Jemez Creek watershed for the present pumped supply. As outlined in the report on the Jemez project prepared by the consulting engineers engaged by the city, the project would comprise two reservoirs on the headwaters of Jemez Creek, the Valle Grande and the San Antonio, with capacities of 12,000 and 15,000 acre-feet, respectively, and a 52-mile pipe line to the city diverting from Jemez Creek near Jemez Springs, about 15 miles below the reservoirs. The project is designed to deliver 6,000 acre-feet of water per year as the requirement of the city when the population will have doubled (estimated to occur in 1965) without any impairment of the natural stream-flow supply as now used for the irrigation of Indian and other lands below Jemez Springs. As to the net effect on the water supply in the Rio Grande, of substituting the Jemez project for the present pumping system, the opinion is expressed by the project's consultants that the present use is undoubtedly a draft, direct or indirect, on Rio Grande; that therefore construction of the Jemez project amounts only to a change in point of diversion; and that since there would be practically no transmission losses with the pipe line, the change would result in a substantial saving of losses by evaporation and seepage which occur under present conditions, in lower Jemez Creek and the Rio Grande, for an equivalent delivery of water to Albuquerque through stream channels.

The water supply for El Paso, with a population of about 110,000, is obtained from 10 wells ranging in depth from 650 to 850 feet. It is indicated that the source of the ground water upon which these wells draw is the precipitation on an extensive area to the east of El Paso. According to data furnished by the superintendent of the city waterworks, the production of the municipal wells in 1936 was 8,800 acre-feet. The average annual production, 1932 to 1936, inclusive, was 8,380 acre-feet. In 1936 the average daily draft during June, the maximum month, was 11.7 million gallons, and during December, the minimum month, 5.5 million gallons. In addition to the municipal wells there are many wells owned and operated by private industries and others. A 1936 survey by the city waterworks indicated an annual production by these wells of about 5,600 acre-feet with a maximum daily draft during summer months of 7.5 million gallons and a minimum in winter months of 3.5 million gallons. With respect to the future of the water supply for El Paso, the following is quoted from a letter of January 12, 1937, from the superintendent of the city waterworks to the engineer in charge of the Rio Grande joint investigation:

> We are contemplating the drilling and construction of three additional wells within the very near future, said construction to be contingent upon the recommendations and advice which will be contained in a report of a survey of the underground water

resources of El Paso and vicinity which was made during 1935 and 1936 by the United States Geological Survey.

The records which this department has maintained over a period of years indicate that the static level of our ground-water supply is slowly receding. This, of course, can mean but one thing; that is, that the pumpage in this area exceeds the recharge.

Should the static level continue to drop during the next 10 or 20 years as it has during the last 15 years, we believe that we shall find it necessary to seek another source of supply. Of course, there is but one other source of supply available and that is the Rio Grande. However, we do not think that it will be necessary for us to use water from that source for several years, if at all.

Use for Power Purposes

The present hydroelectric plants of 100 horsepower or more in the upper Rio Grande Basin are listed in table 98. As indicated, the total of installed horsepower is only 390. At the present time Caballo Dam is under construction on Rio Grande, 25 miles below Elephant Butte Dam. As planned, the reservoir formed by this dam will have a capacity of 350,000 acre-feet to serve the dual purposes of flood control—for which 100,000 acre-feet of capacity is reserved—and re-regulation for irrigation such that firm power can be developed at Elephant Butte Dam. When Elephant Butte Dam was constructed, gates and six penstock openings were built into it in anticipation of future power development. Without re-regulation below the dam, water must be released from the reservoir in accordance with the irrigation demand and releases of this character will not permit development of firm continuous power. With Caballo Reservoir under construction, the Bureau of Reclamation has given tentative consideration to an installation at Elephant Butte Dam of 25,000 kilowatts. Operation studies of the Bureau indicate a possible development of 95 million kilowatt-hours annually with no loss to the water supply of the Rio Grande project or waste. The captured Elephant Butte spills and arroyo inflow to Caballo Reservoir are estimated to offset any losses due to increased evaporation at Elephant Butte and Caballo Reservoirs and to minor spills from Caballo Reservoir in the winter.

TABLE 98.—*Hydroelectric plants of 100 horsepower or more in Upper Rio Grande Basin*

State	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	Rio Grande (Elephant Butte Dam).	Bureau of Reclamation.	[illegible]	150
Do	Santa Fe Creek	[illegible] Co.	Standby for city of Santa Fe.	100
Do	Rio Colorado	Molybdenum Corporation of America.	[illegible]	[illegible]
Total				[illegible]

As noted in subsequent sections of this report, the Bureau of Reclamation is investigating the possibilities of power development in connection with the proposed Wagon Wheel Gap Reservoir on Rio Grande in Colorado and with the San Juan-Chama transmountain diversion. With irrigation the primary and paramount use for water in the Upper Rio Grande Basin, and with shortages in the available water supplies to meet completely the demands for that use, the rule rather than the exception, the development of water power on these projects, or on any others proposed must, as in the case of the Caballo project, be so coordinated with irrigation requirements that the primary position of the latter is fully maintained.

PART I

SECTION 5.—STORAGE DEVELOPMENT

Present Development

Practically all storage development to date in the Upper Rio Grande Basin, by reservoirs of 1,000 acre-feet capacity or more, has been for irrigation purposes. Tables 99 and 100 list those reservoirs in the Rio Grande Basin of Colorado and New Mexico, respectively, of 1,000 acre-feet capacity or more, which are constructed and in operation. All of them are operated solely for irrigation. At Elephant Butte Dam there is a small 150-kilowatt power unit which is operated incidentally to serve the storage works, camp and adjacent recreational area.

Although the need for storage to regulate the water supply of the upper Rio Grande and Conejos basins for irrigation in San Luis Valley was indicated in the early nineties, construction on any large scale was prevented by the embargo as previously explained. This was effective until 1925, and since 1929 storage development of magnitude has been limited by the terms of the Rio Grande Compact. As indicated by table 99, the major storage development for San Luis Valley lands that could be accomplished notwithstanding the embargo, took place in the period from about 1908 to 1914. Of the present total storage capacity of 309,134 acre-feet in the Rio Grande Basin of Colorado, it is to be noted that 136,868 acre-feet capacity is in the southeast area. Here the stream flow is now fully, or almost fully, regulated and utilized. The same is more or less true with respect to Alamosa and La Jara Creeks, controlled by Terrace and La Jara Reservoirs, respectively, in the southwest area. There is no storage on the Conejos River and tributaries and that in the upper Rio Grande drainage above the valley has a combined capacity of 130,804 acre-feet.

The first major storage development in the Rio Grande Basin of New Mexico was the Elephant Butte Reservoir, completed in 1916 with a capacity of 2,638,900 acre-feet. As previously stated, this was built by the Bureau of Reclamation to insure fulfillment of the delivery of water to Mexico in accordance with the treaty of 1906 and to furnish a water supply for the Rio Grande Project. The original capacity has been diminished by the deposition of silt. Data on the accumulation of silt and the resulting reduction in capacity as given in table 101 are taken from Technical Bulletin No. 524, Department of Agriculture, July 1936,

TABLE 100.—*Reservoirs constructed and operated in the Rio Grande Basin of New Mexico, of 1,000 acre-feet capacity or more*

Reservoir	Local drainage	Year completed	Capacity in acre-feet	Remarks
Elephant Butte	Rio Grande	1916	[1] 2,273,700	Rio Grande project, Bureau of Reclamation.
Childers	Smith Lake	1917	1,000	
Costilla	Costilla	1920	20,750	Owned by Costilla Estates Development Co.
Bluewater	Bluewater	1927	57,500	Owned by Bluewater Toltec Irrigation District.
Santa Cruz	Santa Cruz	1929	4,600	Owned by Santa Cruz Irrigation District.
El Vado	Chama	1935	198,000	Owned by Middle Rio Grande Conservancy District.
Carson	Aguaje de la Petaca.	1936	7,430	Owned by Carson Irrigation District.
Total capacity			2,562,980	

[1] By silt survey of 1935.

TABLE 99.—*Reservoirs constructed and operated in the Rio Grande Basin of Colorado, of 1,000 acre-feet capacity or more*

Reservoir	Local drainage	Unit of San Luis section	Year completed	Capacity in acre-feet	Remarks
Cove Lake	San Antonio	Southwest area	1883	9,710	
Regan	House Canyon	do	1908	1,200	
Eastdale no. 1	Culebra-Costilla	Southeast area	1910	3,468	
Eastdale no. 2	do	do	1910	3,041	
La Jara	La Jara	Southwest area	1910	14,052	
Sanchez	Culebra	Southeast area	1911	104,000	
Terrace	Alamosa	Southwest area	1912	17,700	Owned by Terrace Irrigation District.
Beaver Park	South Fork, Rio Grande	do	1912	4,400	Owned by Mosca Irrigation District.
Lost Lakes	Headwaters, Rio Grande	do	1912	2,575	
Road Canyon	Road Canyon	do	1912	2,800	
Rio Grande	Rio Grande	do	1913	51,113	Owned by San Luis Valley Irrigation District.
Santa Maria	Clear	do	1913	42,000	Owned by water users under Rio Grande and Monte Vista Canals.
Mountain Home	Trinchera	Southeast area	1913	20,147	Owned by Trinchera Irrigation District.
Smith	do	do	1914	6,212	Do.
Continental	Clear	Southwest area	1928	26,716	Owned by Del Norte Irrigation District.
Total capacity, southwest area				172,266	
Total capacity, southeast area				136,868	
Total capacity				309,134	

"Silting of Reservoirs." This shows the capacity to have been 2,273,700 acre-feet in April 1935, a reduction from original capacity of 365,200 acre-feet or an average capacity loss in 20 years of 18,000 acre-feet per year.

In the period since its completion, Elephant Butte Reservoir has accomplished the complete regulation of the flow of Rio Grande at San Marcial. Only twice in the period, first in 1920, and again in 1924, has the water level reached the elevation of the bottom of the spillway gates. In 1924 there was some release of water in excess of project demands which might otherwise have been spilled. From table 24, which gives the storage content on the first of each month, 1915 to 1935, it is to be noted that the lowest content since the reservoir filled was reached on May 1, 1935, and that it was then 436,000 acre-feet.

TABLE 101.—[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]		[illegible]	[illegible]

The other reservoirs listed in table 100 are on tributary streams and with the exception of El Vado provide more or less complete regulation of flow. As shown by table 174 of Appendix A, the estimated mean annual run-off of Rio Chama above El Vado Reservoir is 329,500 acre-feet. The extent to which this flow may be regulated by El Vado Reservoir is indicated in a subsequent section of this report in which an operation study of the reservoir is made as an incident to an analysis of the effect on Middle and Elephant Butte-Fort Quitman sections of present irrigation development in San Luis Valley and given diversion demands in the two sections (Condition No. 2). It is found that in the 25-year period, 1911–35, the reservoir would have spilled in every year except 1931 and 1934, and that the average annual spill for the period would have been 206,000 acre-feet.

At the present time, a dam is under construction on Rio Grande about 25 miles below Elephant Butte Dam. This will form the Caballo Reservoir of 350,000 acre-feet capacity. As planned by the American Section of the International Boundary Commission and the Bureau of Reclamation, the latter of which is supervising the construction of the dam, the purpose of this reservoir is to provide (1) flood control for the arroyos between Elephant Butte and Caballo, (2) control and stabilization of the river channel as now rectified below El Paso and as planned to be rectified from Caballo to El Paso, and (3) re-regulation such that firm power may be developed at Elephant Butte Dam. Of the total capacity, 100,000 acre-feet is to be reserved for flood control.

Proposed Development

Colorado Projects

As stated by representatives of Colorado, the major problem concerned with water utilization in San Luis Valley is provision of sufficient storage capacity to so regulate stream flow that diversions may conform to and parallel the irrigation demand of the lands that are now irrigated. This applies chiefly to the upper Rio Grande and the lands served by diversions above Alamosa and to the Conejos River and tributaries and the lands irrigated thereunder. For reasons previously explained, this major problem is not concerned with storage in the southeast area, in the closed basin, or on other streams of the southwest area. Except for the regulation provided by the 131,000 acre-feet of storage capacity on Rio Grande, the lands under Rio Grande and Conejos River and tributaries are dependent on

the run of the stream. As a result, seasonal water shortages occur nearly every year and there are frequent occurrences of severe annual shortages. The lack of conformity between the monthly distribution of supply and diversions and the ideal irrigation demand is indicated by table 102 and figure 36. The monthly distribution of these quantities is given for Rio Grande above Alamosa for 1935, a year of 97 percent normal run-off, and for 1936 when the run-off was 67 percent normal. In the distribution of diversions a segregation was made for the Farmers' Union canal of the San Luis Valley Irrigation District. This district owns and operates the Rio Grande reservoir and has, more nearly than other systems, sufficient storage to regulate supply to irrigation demands. The distribution shown for ideal irrigation demand is that developed and used by R. J. Tipton, consultant to the Colorado State Engineer, in a manuscript report of March 1930. It was derived from an extensive compilation of the diversions by Farmers' Union canal and other canals having old priorities and from the distribution of demand in other comparable regions having adequate storage control. As indicated by figure 36, there is a wide divergence between the water supply and the demand in July and August, and even in June in a year of low run-off like 1936. In the case of the Farmers' Union canal diversions, there is a better approach to the ideal demand in these months, but there was still a heavy overdiversion in June of 1935 and throughout the spring of 1936. In the Conejos area the lack of conformity is more pronounced. With no storage whatever and the spring run-off generally culminating earlier than on Rio Grande, there is a very large overdiversion in the spring months and a shortage in the summer months. Early in the history of irrigation in San Luis Valley the necessity of utilizing the run-off of the streams to greatest possible advantage, combined with favorable soil conditions in the western portion of the valley, lead to adoption of the subirrigation method which has prevailed ever since. By this method the spring overdiversions are largely used to bring up and maintain the ground water close to the plant roots. As far as it may be so effective, this constitutes a substitution of water storage underground for surface reservoir storage. It results, however, in an excessive consumption of water, particularly in the central and eastern portions of the closed basin, where the high water table feeds the transpiration of a large area of native vegetation.

In order to assure a seasonal distribution of water supply in accordance with irrigation demand as well as to provide carry-over storage to reduce annual shortages, the water users of San Luis Valley under the Rio Grande and Conejos River have for many years proposed certain major storage developments on these streams. As a part of the Rio Grande joint investigation, the Bureau of Reclamation undertook an investigation of these storage projects, and a progress report thereon was submitted in March 1937. Investigations of certain of the projects were continuing at this writing, June 1937. Final data and results are incorporated in Part V of this report. The following paragraphs summarize the results of this investigation as presented in the March 1937 progress report. In a subsequent section of this report on the availability and use of water under given conditions, analyses are made of the effect on San Luis, Middle, and Elephant Butte-Fort Quitman sections of the prospective operation of these reservoirs under various combinations of storage and irrigation draft.

Wagon Wheel Gap Reservoir.—The site of this reservoir is on the main stem of Rio Grande 32 miles above

TABLE 102.—*Comparison of monthly distribution of water supply, diversions, and ideal irrigation demand, Rio Grande and Conejos River*

Month	Rio Grande above Alamaso								Conejos River and Tributaries			
	1935—Run-off 97 percent normal				1936—Run-off 67 percent normal				1936—Run-off 90 percent normal			
	Rio Grande near Del Norte	All diversions less Farmers' Union canal	Diversion Farmers' Union canal	Ideal irrigation demand	Rio Grande near Del Norte	All diversions less Farmers' Union canal	Diversion Farmers' Union canal	Ideal irrigation demand	Conejos River and tributaries	Diversions	Consumption	Ideal irrigation demand
	Monthly quantities in percent of seasonal											
January	1.2			—	2.0	—			0.9		—	
February	1.3	0.6	1.5		2.1	0.2			1.1			
March	2.2	2.1	.3		2.9	[illegible]			1.7	2.5	1.1	
April	5.4	5.7	3.8	[illegible]	14.2	15.1	13.6	[illegible]	28.2	15.4	23.8	5
May	12.0	11.4	6.6	17	30.0	30.6	35.1	17	[illegible]	37.2	31.2	17
June	38.5	34.8	41.3	27	18.9	[illegible]	35.1	[illegible]	[illegible]	23.0	19.9	27
July	18.7	22.0	25.0	[illegible]	8.4	8.1	16.2	[illegible]	[illegible]	6.6	5.9	26
August	10.6	11.3	19.9	18	8.0	10.7	[illegible]	[illegible]	4.9	6.2	7.4	18
September	4.1	5.9	1.6	[illegible]	[illegible]	8.0		[illegible]	3.4	3.3	4.9	5
October	[illegible]	4.0	—	2	3.2	4.8		[illegible]	3.8	3.8	3.8	2
November	1.9	2.2	—	—	2.6	.8			3.3	2.0	2.0	
December	1.2	—	—	—	2.0	—			1.8			

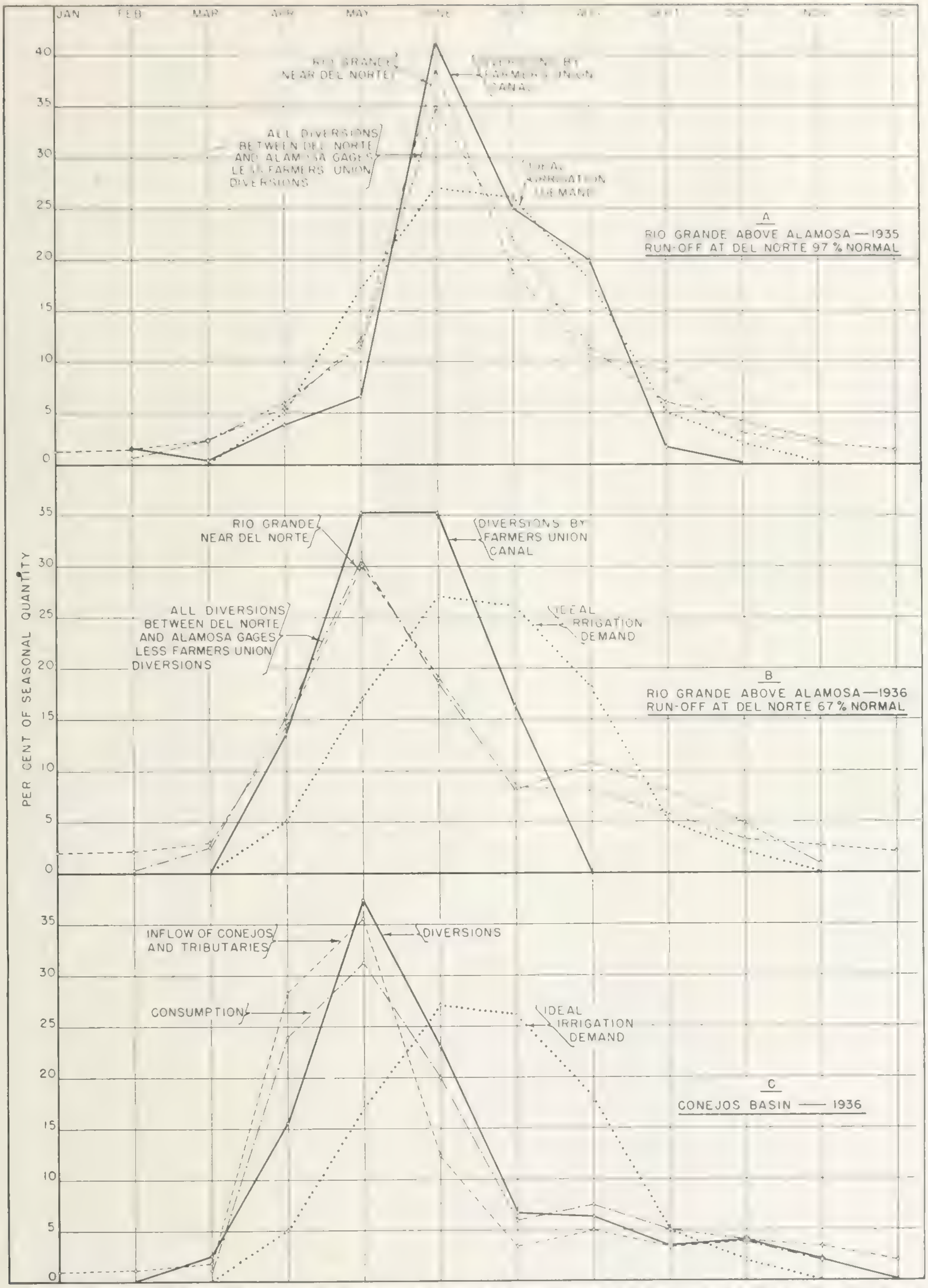


FIGURE 36.—Comparison of monthly distribution of water supply, diversions, and ideal irrigation demand Rio Grande and Conejos River, San Luis Valley, Colo.

Del Norte, Colo. The dam site is about 9 miles southeast of Creede and the Creede branch of the Denver & Rio Grande Western Railroad runs directly through it. The investigation as reported was limited to a survey of the dam site, geological exploration and drilling, and a preliminary plan and estimate for a reservoir with a capacity of 1,000,000 acre-feet. The normal water surface elevation for this capacity is 8,773, and the reservoir area at this elevation is 8,500 acres. Land in the reservoir area is largely, if not wholly, privately owned. The geological investigation of the reservoir gives no indication of unsatisfactory conditions. Normal seep and spring occurrences indicate a water table tributary to the river and the volcanic rock and compact Creede sedimentaries filling the older Rio Grande Channel and mantling the basin indicate that little, if any, reservoir seepage could occur. At the dam site the walls of the canyon are sheer. The rock forming the foundation and abutments is andesite or latite, massive, hard, and competent. In the center of the canyon drilling has shown an 80-foot depth above bed rock of boulders, cobbles, gravel, and sand in a loose, porous deposit which it would be necessary to remove. The site is well adapted to a concrete-arch type of dam. Studies and estimates were made for a concrete gravity dam as well as for other sections of arch dams. Ample deposits of sand and gravel of good quality are located both upstream and downstream from the damsite. The dam for which the estimate is reported is of the constant angle arch type, 1,200 feet long at the crest with a maximum height of 430 feet above the foundation. A straight uncontrolled overflow type of spillway 140 feet long at crest elevation of 8,773 would be located in a saddle approximately 560 feet from the right abutment. With the water at its maximum elevation of 8,780, or 7 feet over the crest, the spillway capacity is 10,000 second-feet. Discharge is to a natural channel leading to the river approximately 1,500 feet downstream from the dam.

In the plans for the dam provision is made for a future power installation by placing two 19-foot diameter tunnels with plugs through the dam for a later installation of two 13-foot diameter penstocks. The estimated cost of the dam, exclusive of cost of power plant, rights-of-way, highway and railroad reconstruction, and property damage, is $9,417,255 or $9.40 per acre-foot of storage. The Wason gage on Rio Grande is within the reservoir site, and as shown by Table 127 of Appendix A the estimated mean annual run-off, 1890–1935, at Wason is 450,600 acre-feet. The drainage area above Wason is 700 square miles. Above the dam site it is 751 square miles, or 107 percent of that above Wason. The mean annual run-off at the dam site was taken as 105 percent of that at Wason, or 473,000 acre-feet.

Summary of data, Wagon Wheel Gap Reservoir

[illegible]

Storage capacity ---- acre-feet --	1,000,000
Spillway capacity ---- second-feet --	10,000
Regulated outlet capacity at 67-foot head ---- do ----	5,000
Elevation top of dam ----	8,780
Normal reservoir water-surface elevation ----	8,773
Maximum reservoir water-surface elevation ----	8,780
River level ----	8,440
Maximum height of dam above bedrock ---- feet --	430
Total estimated cost of dam [1] ----	$9,417,255
Estimated mean annual run-off to reservoir, 1890–1935 ---- acre-feet --	473,000
Drainage area ---- square miles --	751

[1] Exclusive of right-of-way, power plant, and reconstruction of railroad and highway.

Vega Sylvestre Reservoir.—The Vega Sylvestre Reservoir is generally considered as an alternative for the Wagon Wheel Gap Reservoir. The site is on the main stem of Rio Grande about 17 miles above Wagon Wheel Gap. There are several important tributaries between the two sites, so that the mean annual run-off, 1890–1935, of the 528 square miles above Vega Sylvestre, estimated at 344,000 acre-feet, is substantially less than that at Wagon Wheel Gap. Estimates and designs as reported are for a capacity of 240,000 acre-feet. This is the capacity that San Luis Valley interests had tentatively selected as best suited to valley needs. Much of the reservoir site is a mountain meadow used for pasture and wild hay. Colorado State Highway No. 149 from Creede to Lake City passes through portions of it and reconstruction of approximately 7 miles of this highway would be required. Geological investigations of the reservoir show that the indicated underlying Creede siltstones are heavily mantled with river and glacial terrace gravels. These detrital materials are unconsolidated and extremely porous, so that ground storage of some magnitude may be expected. However, there is no reason to suspect an unsatisfactory reservoir basin. Normal spring and seep occurrences indicate a water table tributary to the river, with remote chance for an inclined or perched condition. Geologically, the dam site must be classified as a poor one as it requires excessive corrective designs and measures to overcome what are inherently dangerous characteristics. In the river bed, porous gravels would be encountered for at least 100 feet beneath the river and they may continue to 150 or 200 feet. For the left abutment there is andesite rock, uniformly hard but somewhat fractured, but on the right abutment rock is so deep that it would not be reached by the dam. Support and impervious properties must rely upon the character of the overlying glacial moraine.

While much more prospecting, testing, and analyzing must be done before the limitations of safe and economical design can be determined, estimates have been

[illegible] Valley, Colo.

made for two tentative plans of development. The dam-site selection is controlled by the relative values for foundation purposes of the materials in the river bed and right abutment. Plan A presents a scheme to secure a deep cut-off in the stable river gravels and avoid so far as possible dependence on the reworked morainic material. A blanket is carried upstream to increase percolation distances. The dam, of rolled earth-fill and rock-fill type, is located in the wide portion of the river bottom where the overlying beds of re-sorted glacial and recent river gravels have been largely eroded. The upper portion of the upstream face has a 3:1 slope and the lower portion a long blanket with variable slopes. The downstream slope varies from 2½:1 in the upper portion to variable slopes approximating 12:1 in the lower portion. A long low dike is required at a low section in the reservoir west of the dam. The spillway, designed for 15,000-second-foot capacity, is located on the left abutment in the andesite rock. Test pits have shown a sufficient supply of suitable materials for construction of the earth embankment at a distance of approximately three-fourths mile below the dam site on the right bank. The estimated cost under plan A, including right-of-way and highway relocation, is $4,825,879, or $20.10 per acre-foot of storage.

Summary of data, Vega Sylvestre Reservoir, plan A

Storage capacity	acre-feet	240,000
Spillway capacity	second-feet	15,000
[illegible]	[illegible]	[illegible]
Elevation top of dam		8,970
Maximum [illegible]		8,962
Height of dam above stream bed	feet	[illegible]
Total estimated cost, [illegible]		$4,825,879
Estimated mean annual run-off [illegible] 1935)	acre-feet	[illegible]
Drainage area	square miles	[illegible]

Plan B presumes that the reworked morainic material is more satisfactory than assumed in plan A and takes advantage of a better profile obtained by swinging the axis of the dam southwesterly and directly across the narrowest portion of the valley. A much deeper cut-off trench is required and extensive blanketing at the upstream toe of the dam. The estimated cost under plan B is $4,524,581, slightly lower than that under plan A, chiefly because of the smaller volume in the embankment.

Conejos Reservoirs.—The original program for investigations on the Conejos River provided only for a survey and exploration of dam site no. 1, about 8 miles above the Mogote gage. This site had been selected several years ago and the reservoir surveyed, but no prospecting had been done. Survey of the dam site, drilling, and test-pit work were carried on simultaneously. It was soon discovered that geological conditions were such that the feasibility of the site was questionable, because of the excessive depth of sand and gravel overburden which extends across the river and under the mammoth landslide comprising the right abutment. Designs and estimates for this site have not been completed, pending a thorough exploration of the right abutment. The main highway from Alamosa over Cumbres Summit into New Mexico passes by the left end of the dam site and crosses the reservoir site about 3 miles above the dam site, and a new secondary road is now being constructed from the river crossing on the main highway to the upper end of the reservoir site. Construction of the reservoir would therefore require relocation of 5 miles of primary highway and 7 miles of secondary highway. Several resort camps and summer homes are within the reservoir area. The reservoir capacity curve derived from the 1925 survey by R. J. Tipton indicates a capacity of 100,000 acre-feet at an elevation approximately 131 feet above the river bed at the dam site. The estimated mean annual run-off, 1890–1935, of the 282 square miles above the Mogote gaging station is 255,600 acre-feet.

Upon discovery of the unfavorable conditions at dam site no. 1, search for other sites was begun and continued until a reconnaissance of the entire river from Mogote to altitudes of more than 10,000 feet had been completed. This resulted in the selection of eight other possible sites. These are described and the extent of the investigations at each of them is detailed in the Bureau of Reclamation report, Part V. Designs and estimates were completed only for the upper Conejos site, designated as No. 6. This is located on the Conejos River about a mile above Platoro in Conejos County, Colo. It is 12.5 miles via gravelled highway from Platoro to the nearest railroad shipping point, Monte Vista. The reservoir is entirely on

Government land within a national forest. The data are:

Summary of data, upper Conejos Reservoir No. 6

[illegible]

Storage capacity	acre-feet	32, 000
Spillway capacity	second-feet	6, 000
Regulated outlet capacity	do	500
Elevation top of dam		10, 010
Maximum reservoir water-surface elevation		10, 005
Maximum height of dam	feet	115
Length of dam	do	540
Length of auxiliary dike	do	400
Height of auxiliary dike	do	38
Reservoir area at spillway level	acres	710
Total estimated cost, dam and reservoir		$608, 404
Cost per acre-foot of storage		$19. 01
Estimated mean annual run-off to reservoir, 1912–35 [1]	acre-feet	48, 700

[1] Estimated by precipitation-altitude method.

One of the other sites investigated, the Mogote, is an offstream site about 3½ miles north of the Conejos River, just at the edge of San Luis Valley. A feeder canal from the river to the reservoir offers no difficulties, but the reservoir basin is possibly 150 feet above the water table and may not be sufficiently tight. Previous surveys have indicated that a capacity of 30,000 acre-feet can be secured at this site with a dam about 90 feet high and 800 feet long. Explorations are now in progress and until these are completed and estimates are made no conclusions can be drawn as to the feasibility of this reservoir.

New Mexico Projects

Except for terminal storage for the San Juan-Chama transmountain diversion project, the only storage project included for investigation under the funds allocated for use in New Mexico was the State Line Reservoir.

State Line Reservoir.—This reservoir on Rio Grande, approximately at the Colorado-New Mexico State line, and the Closed Basin Drain are recommended in the present Rio Grande Compact signed in 1929 in the following language:

> * * * That for the economic development and conservation of the waters of the Rio Grande Basin and for the fullest realization of the purposes recited in the preamble to this compact, it is of primary importance that the area in Colorado known as the closed basin be drained, and the water thus recovered be added to the flow of the river, and that a reservoir be constructed in Colorado upon the river, at or near the site generally described as the State Line Reservoir site. The installation of the drain will materially augment the flow of the river, and the construction of the reservoir will so regulate the flow as to remove forever the principal causes of the difficulties between the States signatory hereto.

At the time the compact was signed it was considered that regulation of the flow of Rio Grande below all

FIGURE [illegible].—[illegible]

Colorado diversions by means of a reservoir at the State line would provide an assurance of flow to New Mexico such as to largely remove one of the principal causes of interstate controversy.

Surveys and explorations at this site were begun late in 1936, but had not been completed at the writing of Part I of this report. They were continuing under a further program of investigation by the Bureau of Reclamation in 1937 the final report of which is given in Part V.

Two sites for the dam have been proposed. The Middle Rio Grande site (Middle Rio Grande Conservancy District), about 1½ miles above the State line, has been surveyed and drilled by the Middle Rio Grande Conservancy District. A dam there, built to elevation 7,570, would have a maximum height of 150 feet and store 750,000 acre-feet. At elevation 7,510 with a maximum height of 90 feet, the capacity would be only about 250,000 acre-feet. The higher elevation would submerge part of the city of Alamosa (elevation 7,550), numerous outlets of drainage ditches in the San Luis Valley, and preclude the drainage of the sump area of the closed basin. An elevation of 7,510 appears to be about the highest level to which water can be stored without undue interference with existing developments. The lack of capacity at such an elevation above the Middle Rio Grande site and an effort to secure more favorable geologic conditions, led to a search for another site farther downstream.

The Costilla River site selected lies just below the mouth of Costilla River, which enters the Rio Grande Canyon from the east about 3 miles below the State line. It is in a box canyon of basaltic rock with almost vertical sides, the top width of the canyon at 7,520 being only about 500 feet. The river surface is at elevation 7,375, or 45 feet lower than at the Middle Rio Grande site. Costilla River lies in a narrow box canyon for almost a mile before it joins Rio Grande, but above this canyon there is a large basin which would increase the storage capacity materially over that available at the Middle Rio Grande site. Drillings at the Costilla River site have disclosed a water table

at approximately elevation 7,471, or 30 feet below the river bed. This implies a rather pervious bed beneath the entire reservoir.

Investigations were in progress at a new site, the Ute Mountain dam site, about 7.5 miles below the Costilla River dam site and about 10.5 miles south of the State line. Springs in the canyon walls here indicate a water table tributary to the river and in conformity with the ground water gradient projected from the Middle Rio Grande and Costilla sites, already drilled. Although a materially higher dam would be required at the Ute Mountain site than at the other sites for a given capacity, the Ute Mountain site holds greater possibilities and provides more storage capacity under the limiting elevation.

Smaller projects.—Although not included for investigation by the Bureau of Reclamation as a part of the Rio Grande joint investigation, there have been a number of smaller storage projects proposed for construction on Rio Grande tributaries in New Mexico. Table 103 gives a list and description of such projects as proposed in applications to the Federal Works Progress Administration or to the Federal Emergency Administration of Public Works. Under the President's Executive Order of September 23, 1935, approval of these projects has been withheld, pending clearance by the National Resources Committee, which, in turn, awaits completion of the Rio Grande joint investigation and report.

Flood Control by Reservoirs

In spite of the damage that may result from them, floods have an economic value in the Upper Rio Grande Basin in flushing the river channel and carrying away the sand and silts that inevitably accumulate during a preceding series of low-water years.

Since the operation of Elephant Butte Reservoir began, the only floods in the Elephant Butte-Fort Quitman section have been the flash floods from tributaries. The reduction of peak discharges in the main river has had the effect of flattening the river slope between the diversion dams and from tributary arroyos has come considerable debris that tends to choke the channel. The combined effect of these two factors is that a comparatively moderate tributary flood may be more serious now than a much larger one was before Elephant Butte Dam was constructed.

In the Middle Valley, the silting of the channel during a series of low water years such as obtained from 1933 to 1936, inclusive, made the moderate freshet of 1937 loom larger than it otherwise deserved.

The maximum recorded flood of the lower portion of the Middle Valley occurred September 22–26, 1929, due to continued rains. At San Marcial the flood peak of September 24 has been estimated at 47,000 second-feet. The town of San Marcial was virtually destroyed. Most of the water came from Rio Puerco, Rio Salado, and other tributaries. The maximum 24-hour discharge of Rio Grande at Otowi Bridge was only 6,540 second-feet on September 23, while Rio Chama contributed a maximum of only 2,480 second-feet on the same date.

In San Luis Valley floods are generally due to rains coinciding with the spring melting of snows, although the maximum recorded discharge was from fall rains. The three highest 24-hour discharges recorded on Rio Grande at Del Norte are:

	Second-feet
June 5, 1905	10,000
October 5, 1911	14,000
June [illegible], 1927	12,600

The highest recorded general flood on Rio Grande occurred during the spring of 1905. That was a generation ago and in that period of time such catastrophies are easily forgotten. During the flood the following maximum 24-hour discharges were recorded:

	Second-feet
June 5 at Del Norte	10,000
June 8 at Lobatos	13,100
June 9 at Otowi Bridge	17,400
June 12 at San Marcial	18,500
June 14 at El Paso	23,600

If Wagon Wheel Gap Reservoir of 1,000,000 acre-feet capacity had been in operation during this flood the

TABLE 103.—[illegible]

[illegible] to	Tributary	County	Reservoir capacity, acre-feet	Type	[illegible]	[illegible]	Estimated cost
W. P. A.	[illegible]	Rio Arriba	[illegible]	Earth	[illegible]	3,000, now under cultivation	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	60	[illegible]	[illegible]
Do.	[illegible]	do.	[illegible]	[illegible]	78	[illegible]	[illegible]
	[illegible]	do.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Do.	[illegible]	[illegible]	[illegible]	[illegible]	140	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	10,50	[illegible]	[illegible]
Do.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]			[illegible]				$3,077,128

[illegible]

reservoir content at the end of April 1905 would have been 138,000 acre-feet. It could have withheld the entire inflow during the following May and June which totaled 381,000 acre-feet. The peak of this flood at Del Norte could, therefore, have been reduced materially, probably to 3,000 or 4,000 second-feet. (Tributary daily flows are not available to permit of a closer estimate.)

Assuming State Line Reservoir had been in operation with a capacity of 460,000 acre-feet (a tentative figure obtained from a preliminary map of 1937 surveys made subsequent to the March 1937 progress report of the Bureau of Reclamation), it would have contained 240,000 acre-feet at the end of April 1905. The Lobatos run-off for May was 178,000 acre-feet, so that the reservoir would have been full and spilling before the peak of 13,100 second-feet on June 8 occurred. The State Line Reservoir operating alone, therefore, would not have had the effect of reducing the flood peak on the river below. If, however, Wagon Wheel Gap Reservoir had also been in operation, the flood peak at Lobatos could have been substantially reduced, with consequent reduction throughout the Middle Valley.

All reservoirs heretofore proposed in the Upper Rio Grande Basin would be primarily for irrigation purposes and unless additional capacity were provided and the reservoir operated so as to preserve the added space for flood storage, it would be necessary to consider any flood control benefit as incidental to irrigation. However, Elephant Butte Reservoir with a capacity twice the normal Rio Grande inflow has effectively reduced Rio Grande flood peaks below it as far as Fort Quitman. Similarly, Wagon Wheel Gap Reservoir, with a proposed capacity twice the normal inflow, should as effectively reduce general flood peaks in San Luis Valley and confer some benefit in this respect on the Middle Valley as well.

PART I

SECTION 6.—ADDITIONAL WATER SUPPLIES BY IMPORTATION AND SALVAGE

With practically the entire water supply of the Upper Rio Grande Basin at present consumed above Fort Quitman, there appear to be only two noteworthy sources to which resort may be had for additional water supplies. One is the importation of water from another drainage basin and the other, the salvage of present wastes and losses within the basin. Although storage in upper parts of the basin may be expected to result in a favorable redistribution of water supply with respect to the lands served, no new water is made available to the basin as a whole, except insofar as the redistribution may effect savings in losses and wastes suffered at present because of the lack of a regulated supply, and presumably a realization of savings is the basis upon which storage for upper-valley lands is to be justified with respect to the lower-valley lands of the basin. Under the heading of additional water supplies for the basin, storage must, therefore, in the last analysis, be placed in the classification of salvage of present wastes and losses in excess of the increased consumption by reservoir evaporation.

Importation

The possibility of importation of water from another drainage basin to augment the supplies of the Upper Rio Grande Basin has long been considered by the water users in the three States of the basin. Of the outside drainage basins to be considered, there is only one which appears to afford reasonable opportunities and to which serious consideration has been given. That is the San Juan Basin of the Colorado River drainage. The diversion of water from the Colorado to the Rio Grande Basin is permissible under the Colorado River compact, and it would afford New Mexico an opportunity to utilize, in greater or less measure, its share of the waters of the Colorado Basin under that compact.

As a part of the Rio Grande joint investigation, the Bureau of Reclamation was assigned to an investigation of and report upon the projects which have been proposed for transmountain diversion of San Juan waters to Rio Grande. Four separate projects—one, the San Juan-Chama, proposed by New Mexico, and three, the Animas-Rio Grande, Weminuche Pass, and San Juan-South Fork Rio Grande, proposed by Colorado—were investigated. The following paragraphs briefly summarize the results of these investigations as presented in a March 1937 progress report of the Bureau of Reclamation. Certain features of these projects were the subject of investigations which were continuing at the time Part I was written. Final data and results are incorporated in Part V of this report. In a subsequent section consideration is given to the possible accomplishments of these diversions under various assumed schedules of operation.

San Juan-Chama Transmountain Diversion

As planned, this project begins with the diversion of Turkey Creek, a tributary of San Juan River, into a reservoir of 70,000 acre-feet capacity on the West Fork of the San Juan River about 14 miles north of Pagosa Springs, Colo. From the bottom of this reservoir, a diversion canal of 300 second-feet capacity carries Turkey Creek and West Fork waters to a 70-foot drop into East Fork about 1 mile above its confluence with the West Fork. About 6 miles upstream, a reservoir of 35,000 acre-feet capacity is planned to regulate the flow of the East Fork. A diversion dam a short distance below the canal drop into the East Fork diverts into a canal of 500 second-feet capacity which lies just above the 7,500-foot contour east of the San Juan River. Coal Creek, Mill Creek, Rito Blanco, and the Blanco River are diverted into the main canal by short feeder canals. On the Blanco River, 5½ miles above the canal crossing, a reservoir of 15,000 acre-feet capacity is planned to regulate the flood flows of that river. From the Blanco River to the Little Navajo River the canal capacity is increased to 700 second-feet and the canal is almost entirely in tunnel. At the lower portal of the tunnel on the Little Navajo River the canal is joined by a diversion canal from the Navajo and Little Navajo Rivers and its capacity is again increased to 800 second-feet. After passing a few miles along the northerly side of the Little Navajo River, the main Navajo River is crossed with a siphon almost a mile long under 350 feet maximum head. At the end of the siphon the canal enters a succession of tunnels and siphons along the south side of the Navajo River to a point about 1½ miles east of Edith and almost on the Colorado-New Mexico boundary line. Continuing nearly due south, the canal traverses several deep cross drainage streams, crosses Amargo Creek and the Denver & Rio Grande Western

R. R. (narrow gage) near Monero, N. Mex., and finally enters a 6-mile tunnel through the Continental Divide beneath Hillcrest on the Jicarilla Indian Reservation. From the lower portal of this tunnel at an elevation of 7,400 feet the water flows in a natural stream bed to Boulder Lake. From the latter, releases may be made to a natural stream channel emptying into El Vado Reservoir.

This system comprises four reservoirs (exclusive of Boulder or Stinking Lakes, alternative terminal reservoirs) with a total capacity of 170,000 acre-feet and a canal system totaling 89.43 miles, of which 17.37 miles are in tunnel. The estimated total cost of the entire project is $22,260,000, or $63.60 per acre-foot of diversion. Of the total cost, $14,786,408 is estimated for the canal system, and $7,440,307 for the West Fork, East Fork, Blanco, Navajo, and Boulder Lake Reservoirs.

The total drainage area contributing to this diversion is 506 square miles, with a mean altitude of 9,688 feet, and the estimated mean annual divertible run-off, 1916–36, is 380,900 acre-feet. Allowing for canal and reservoir losses, the mean annual net delivery of regulated water to Rio Chama above El Vado Reservoir is estimated at 350,000 acre-feet. This yield would be decreased by the San Juan-South Fork Rio Grande transmountain diversion project. The system is designed to deliver an almost constant supply to the terminal reservoir from March to December, inclusive.

Existing developments in the San Juan Basin as far down as Shiprock, N. Mex., would not be impaired by this diversion, but if future developments of any extensive San Juan areas are found to be feasible, an additional reservoir either on the San Juan River or a tributary may be found necessary to avoid conflict in water supplies.

Summary of data, San Juan-Chama transmountain diversion

(See Part V, this report, for alternate lower cost diversion finally developed.)

Contributing San Juan drainage area, square miles	506
Estimated mean annual delivery to Rio Chama, 1916–36, acre-feet	350, 000
Estimated total cost	$22, 260, 000
Estimated cost per acre-foot of diversion	$63. 60
Elevation of highest diversion (from Turkey Creek)	7, 890
Elevation of Continental Divide tunnel outlet	7, 400
Maximum water-surface elevation Boulder Lake, terminal reservoir	7, 305
Canal system:	
Main canal capacity, second-feet	300 to 800
Earth canals, miles	52. 39
Concrete lined canals, do	15. 17
Bench flumes, do	. 46
Tunnels, do	17. 37
Siphons, do	4. 04
Total length of conduits, do	89. 43
Reservoirs:	
West Fork San Juan:	
Capacity, acre-feet	[illegible]
Type of dam: Compacted embankment.	
Height of dam, feet	150
East Fork San Juan:	
Capacity, acre-feet	35, 000
Type of dam: Compacted embankment.	
Height of dam, feet	150
Blanco:	
Capacity, acre-feet	15, 000
Type of dam: Compacted embankment.	
Height of dam, feet	102
Navajo:	
Capacity, acre-feet	50, 000
Type of dam: Compacted embankment.	
Height of dam, feet	120
Boulder Lake (terminal reservoir):	
Capacity, acre-feet	290, 000
Outlet capacity, second-feet	2, 000
Type of dam: Compacted embankment.	
Height of dam, feet	138
Stinking Lake (alternate terminal reservoir):	
Active capacity, acre-feet	500, 000
Outlet capacity at low levels, second-feet	1, 000
Type of dam: Compacted embankment.	
Height of dam, feet	115

Animas-Rio Grande Transmountain Diversion

This project contemplates a diversion from the upper reaches of the Animas River, a tributary of San Juan River, to the headwaters of Rio Grande in Colorado. Under the plan for which designs and estimates were made the South Fork of Mineral Creek, Mineral Creek, and Cement Creek would be diverted to a reservoir at Howardsville on the main Animas River near Silverton, Colo. From the Howardsville Reservoir a tunnel would carry the water eastward through the Continental Divide to the upper reaches of Rio Grande about 60 feet above and a mile from the high water line of the existing Rio Grande Reservoir. The highest diversion, that from the South Fork of Mineral Creek, is at elevation 9,852 and bottom grade elevations at the west and east portals of the main tunnel to the Rio Grande are, respectively, 9,698 and 9,612.

The entire project comprises 13.66 miles of conduit in the collection system, including 2.56 miles of tunnel, 12.98 miles of main tunnel, 400 second-feet capacity, and the Howardsville Reservoir of 53,000 acre-feet capacity. The estimated total cost is $10,432,496, or $79.00 per acre-foot of diversion.

The drainage area above 9,800 feet elevation contributing to this diversion is 129 square miles. The estimated mean annual divertible run-off, 1916–35, is 144,000 acre-feet. For the period 1924–35 it is 130,700 acre-feet. The run-off which it is estimated could have been diverted 80 percent of the time is 122,000 acre-feet.

In the minimum year of 1934 only 43,000 acre-feet could have been diverted.

A tentative study of discharges of the Animas River at Tacoma and Durango, depleted for possible diversions to Rio Grande for every month from 1911 to date, indicates that no shortages would have occurred at any time in the 24-year period. It appears, therefore, that the proposed diversions may be made without impairing existing rights or obstructing future developments now considered feasible.

Summary of data, Animas-Rio Grande transmountain diversion

Contributing Animas drainage area..square miles..	129
Estimated mean annual divertible run-off, 1924–35 acre-feet..	130, 700
Estimated total cost..........................	$10, 432, 496
Estimated cost per acre-foot of diversion..........	$80. 00
Elevation of highest diversion (South Fork Mineral Creek)..............................	9, 852
Elevation of Continental Divide Tunnel outlet...	9, 612
Collection system:	
Earth canal.........................miles..	1. 14
Combination section...................do....	8. 62
Bench flume..........................do....	0. 49
Cut and cover section..................do....	0. 85
Tunnel...............................do....	2. 56
Total length of collection conduits.....do....	13. 66
Animas-Rio Grande tunnel:	
Capacity.......................second-feet..	400
Diameter............................feet..	9. 5
Length..............................miles..	12. 98
Howardsville Reservoir:	
Capacity.......................acre-feet..	53, 000
Type of dam: Earth embankment.	
Height of dam.......................feet..	255

Weminuche Pass Transmountain Diversion

This project contemplates a diversion from the headwaters of Pine River, a tributary of San Juan River, to the headwaters of Rio Grande in Colorado. The plan as developed calls for the diversion of two creeks, one on each side of Pine River at elevation 10,500, to the main stream at the head of the pass and then through the divide by means of a long cut. The canal discharges into an unnamed creek which flows into the existing Rio Grande Reservoir about 3 miles below. The estimated total cost is $264,500, or about $13 per acre-foot of diversion.

The drainage area above 10,500 feet elevation contributing to this diversion is 24 square miles and the estimated mean annual divertible run-off, 1924–35, is 20,455 acre-feet. However, this yield is after allowance has been made for no diversions in 1925, 1931, and 1934 because of interference with storage development on the Pine River project near Bayfield, and after prior transmountain diversion rights of 4,000 acre-feet have been deducted.

Summary of data, Weminuche Pass transmountain diversion

Contributing Pine River drainage area square miles..	24
Estimated mean annual divertible run-off, 1924–35 [1]..............................acre-feet..	20, 455
Estimated total cost..........................	$264, 500
Estimated cost per acre-foot of diversion..........	$13. 00
Elevation of highest diversion..................	10, 500
Total length of canal...................miles..	7. 5

[1] [illegible]

San Juan-South Fork Rio Grande Transmountain Diversion

This project contemplates a diversion from the headwaters of San Juan River, above the diversion of the San Juan-Chama project, to the South Fork of Rio Grande. The South Fork joins Rio Grande about half way between Del Norte and Wagon Wheel Gap. The plan for which designs and estimates were made provides for the diversion of the West Fork of San Juan River to Beaver Creek by a canal 2.6 miles long, of which 2,400 feet are bench flume. From Beaver Creek an 8-foot tunnel, 3.2 miles long and of 425 second-feet capacity, carries the water southeasterly to meet a tunnel of the same size and 1.0 mile long from Wolf Creek. A 9-foot tunnel, 6.7 miles long and of 525 second-feet capacity, then leads from the junction to the South Fork of Rio Grande. It would require 7 miles of difficult road construction to gain access to the West Fork diversion and the Beaver Creek portal. The South Fork portal is within a half mile of the main graveled highway over Wolf Creek summit, which also passes within 200 feet of the Wolf Creek portal. The latter is approximately 15 miles from the Creede branch of the Denver & Rio Grande Railroad. The estimated total cost of the project is $5,290,306, or about $100 per acre-foot of diversion.

The drainage area above an altitude of 9,050 feet contributing to this diversion is 45 square miles, and the estimated mean annual divertible run-off, 1916–36, is 53,000 acre-feet. In the minimum year of 1934 the yield would have been only 23,000 acre-feet. No existing rights on the San Juan below the diversion would be impaired, but the supply available for the San Juan-Chama diversion would be depleted by the amount diverted to the South Fork of Rio Grande.

Summary of data, San Juan-South Fork Rio Grande transmountain diversion

Contributing San Juan drainage area square miles..	45
Estimated mean annual divertible run-off, 1916–36 acre-feet..	53, 000
Estimated total cost..........................	$5, 290, 306
Estimated cost per acre-foot of diversion..........	$99. 80
Length of feeder canal West Fork to Beaver Creek miles..	2. 6

Summary of data, San Juan-South Fork Rio Grande transmountain diversion—Continued

Tunnel, Beaver Creek to Junction:	
Length ____ miles__	3. 2
Diameter ____ feet__	8. 0
Capacity ____ second-feet__	425
Tunnel, Wolf Creek to Junction:	
Length ____ miles__	1. 0
Diameter ____ feet__	8. 0
Tunnel, Junction to South Fork:	
Length ____ miles__	6. 7
Diameter ____ feet__	9. 0
Capacity ____ second-feet__	525
Total length of tunnels ____ miles__	10. 9

Salvage

In table 83 of the previous section on water uses and requirements it is shown that for the entire Upper Rio Grande Basin approximately half only of the stream flow consumed is by the irrigated acreage; that the other half is consumed by losses, avoidable and unavoidable. Consumption on areas other than the irrigated acreage is, in tables 76 to 81, segregated to native vegetation and miscellaneous. The miscellaneous item includes consumption by the area of towns and villages; land temporarily out of cropping; water surfaces, including pooled water, river and canal surfaces, and exposed beds; and bare lands, including roads, rights-of-way, and the like. It is in the item of consumption by native vegetation that the chief opportunity lies for saving water.

Nonbeneficial Consumption by Native Vegetation

The consumption by areas of native vegetation is the result of a high-water table from which the vegetation may readily draw its supply. The high-water table is the result of seepage from streams and canals but chiefly from irrigated lands with inadequate drainage, or without drainage, upon which overdiversions may have been applied in an endeavor to utilize to the fullest extent the peaks of an unregulated water supply. However, without drainage, the normal diversions from a regulated supply have resulted in time in a high-water table and in a waterlogged condition. Lowering the water table by drainage so that the supply of water to native vegetation would be cut off is, therefore, the solution to water recovery in any plan to take advantage of the chief opportunity for salvage.

The acreages and consumption (including precipitation) under the three classifications of irrigated lands, native vegetation, and miscellaneous are given in table 77 for San Luis section and in tables 79 and 81 for the main stem of Rio Grande in Middle and Elephant Butte-Fort Quitman sections. Comparison of the totals of consumption for these three classifications shows that irrigated lands and native vegetation each account for 44 percent of the combined total of the three. Converting the consumption figures for native vegetation to stream-flow depletion by correcting for precipitation gives the data of table 104. This shows four areas of particularly large stream-flow depletion by native vegetation; the closed basin and southwest areas in San Luis Valley, the Middle Rio Grande Conservancy District area, and the Rio Grande area from San Marcial to Percha Heading. Of these, the indicated depletion of 339,000 acre-feet in the closed basin is by far the largest. This should be expected in view of the conditions conducive to evapo-transpiration losses inherent in a closed basin of this character. The distribution of the native vegetation given in table 104 within the various units listed is shown on the large scale maps of vegetative cover, plates 10 to 22. In the closed basin it is mostly confined to the eastern half, which includes the large sump area, and to scattered bordering areas below tributary streams. In the southwest area it is scattered throughout the irrigated area to considerable extent, although there are some larger blocks which are practically all native grass and brush and which are drawing on ground water that has seeped from irrigated lands.

TABLE 104.—*Estimate of stream flow depletion by native vegetation, Upper Rio Grande Basin* [1]

Basin unit	Native vegetation acreage, 1936	Stream-flow depletion	
		Acre-feet	Acre feet per acre
SAN LUIS SECTION			
Closed basin area	404, 014	339, 400	0. 84
Southwest area	176, 191	165, 600	. 94
Southeast area	156, 994	[illegible]	. 48
Total	737, 199	580, 400	. 79
MIDDLE SECTION—MAIN STEM RIO GRANDE			
Colorado State Line to Otowi Bridge	3, 651	9, 200	2. 52
Middle Rio Grande Conservancy District	90, 401	241, 400	2. 67
Bosque del Apache Grant and below to San Marcial	12, 781	[illegible]	[illegible]
Total	106, 833	312, 100	2. 92
ELEPHANT BUTTE-FORT QUITMAN SECTION—MAIN STEM RIO GRANDE			
San Marcial to Percha Heading	[illegible]	120, 100	4. 07
Rio Grande project	30, 561	82, 500	2. 70
Hudspeth County Conservation and Reclamation District	5, 899	18, 500	3. 13
Total	65, 966	221, 100	3. 35
Total of sections	910, 000	1, 113, 600	1. 22

[1] Derived from Bureau of Agricultural Engineering consumptive use estimates of tables 77, 79, and 81 by subtracting normal precipitation.

In the Middle Rio Grande Conservancy District there are many scattered areas where the drainage system has been only partially effective or wholly ineffective in lowering the ground water, and these areas are supporting native vegetation which is largely grass and bosque. Outside of the district boundaries there are a number of undrained areas in the Middle Valley

upon which heavy growths of native vegetation are consuming large quantities of water. The largest of these is that portion of the Bosque del Apache Grant within the Rio Grande flood plain.

Outside of an area of heavy consumption by native vegetation at the upper end of Elephant Butte Reservoir and along the river between Elephant Butte and Percha Dam, such consumption in the Elephant Butte-Fort Quitman section is largely on scattered small areas within the Rio Grande Project and somewhat larger areas along the river in Hudspeth County.

Data are not available to permit even an approximate determination of the total amount of water which might be feasibly and economically recovered from the million acre-feet or more by which the stream flow is annually depleted in supporting the growth of native vegetation in the Upper Rio Grande Basin. It seems unquestionable, however, that some fraction of this loss should be susceptible of economic recovery by proper drainage construction. There is still a great amount of land which is undrained.

Status of Drainage

As listed in table 105 there are 15 drainage systems in the southwest and closed basin areas of San Luis Valley, besides a large number of roadside drains not included in any system. The gross area under these 15 systems is 206,000 acres, of which 75,000 acres are in the southwest area and 131,000 in the closed basin. The Rio Grande Drainage District area of 30,000 acres in the closed basin drains to Rio Grande, but the other closed basin systems drain to the sump of that basin. The drainage systems of the Rio Grande District and the San Luis Valley Irrigation District have made possible the cultivation of the lands north of Alamosa and east of the chief agricultural region lying between Monte Vista and Center and on the higher slopes below the Rio Grande canal. In the southwest area drainage has been effective in relieving seepage over much of the area below the Monte Vista and Empire canals with the exception of a strip about 6 miles wide just west of Rio Grande where wild hay is grown.

The total irrigated and water-consuming acreage as mapped in the closed basin is 733,000 acres, and in the southwest area 483,000 acres. Of these totals, 334,000 acres in the closed basin and 235,000 acres in the southwest area are served from Rio Grande. Comparing with these figures the gross acreage under drainage systems as given in table 105, it will be seen that the drained area in the closed basin represents 18 and 39 percent, respectively, of the basin's total watered area and the portion served from Rio Grande, and that the southwest drained area represents 16 and 32 percent, respectively, of the total southwest area and its portion served from Rio Grande.

TABLE 105.—*Drainage systems in San Luis Valley*

[illegible]	[illegible]	[illegible] pleted	[illegible] drains
TRIBUTARY TO RIO GRANDE[1]			
[illegible]	6,000	[illegible]	[illegible]
[illegible]	5,040	[illegible]	32
[illegible]	2,080	1915	[illegible]
[illegible]	900	1917	[illegible]
[illegible]	11,000	1918	40
[illegible]	30,000	[illegible]	[illegible]
[illegible]	1,000	1922	[illegible]
[illegible]	1,440	[illegible]	[illegible]
[illegible]	9,300	1923	[illegible]
[illegible]	12,900	[illegible]	42
[illegible]	13,400	1924	29
[illegible]	11,800	[illegible]	30
Total	[illegible]		[illegible]
TRIBUTARY TO SUMP, CLOSED BASIN			
[illegible]	[illegible]	1910	[illegible]
[illegible]	24,000	1913	[illegible]
San Luis Valley Irrigation District	67,000	[illegible]	[illegible]
[illegible]	101,400		[illegible]

[illegible]

The development of drainage in San Luis Valley has been such as to afford an opportunity for extensive rediversion of the drain water to irrigate lower lying lands, or to check the drains during the irrigation season so as to hold up the water table in the area where subirrigation is practiced. The effect has been to reduce what would be a normal river return. It appears probable that a continuation of this diversion and reuse of drain water may be anticipated under future drainage development. This applies more particularly perhaps to the closed basin than to the southwest area. As further drainage is developed along the eastern border of the present irrigated lands occupying the western half of the closed basin, opportunity will be afforded for the progressive reclamation to the east of the lands which were cultivated many years ago but were subsequently abandoned when they became seeped. Much of the eastern lands can probably be reclaimed and irrigated from drain diversions in this way, and with future storage development for the valley limited in purpose to equalization of the water supply of the present irrigated acreage, the drainage water is practically the sole source available for such eastern extensions. However, since, as shown by table 77, the consumption per acre in the closed basin by irrigated lands and native vegetation is about the same, the drainage of an area of native vegetation should supply an equivalent area of irrigated crops.

In the Middle Valley the present open drain system of the Middle Rio Grande Conservancy District was completed between 1930 and 1935. It drains the area from Cochiti to the northern boundary of the Bosque del Apache Grant, except for one or two tracts along the river on the east side which are not included in the dis-

trict. As indicated in the section of this report dealing with ground water the average lowering of the water table in the conservancy district due to the drainage construction was 3 feet, and the maximum average lowering for any one area of the district was 3.67 feet in the Peralta-Tome area. Drainage has not been completely effective over the whole district, as there are still numerous small areas where the water table is high. This is particularly true with respect to areas adjacent to the river outlets of riverside drains where the gradients of the latter are necessarily very flat, and in the bosque areas bordering the river in the lower divisions. There are no drainage systems in the Middle Valley outside of the conservancy district and, as indicated by the 1936 survey, the undrained area of high water table between the southern boundary of the district and San Marcial totals about 17,000 acres.

In the Elephant Butte-Fort Quitman section, drainage is effective and practically complete within the area of the Rio Grande Project from Percha Dam to the Hudspeth County Line. In the Hudspeth County Conservation and Reclamation District a complete system of open drains has been under construction during the past few years and is now virtually completed.

Proposed Sump Drain

There is one project for the salvage of waters now lost by evaporation and transpiration by nonbeneficial vegetation, which has in recent years received much consideration and study as to feasibility and probable water yield. It is the so-called sump drain, a trunk drain proposed to collect the waters in the sump area of the closed basin, San Luis Valley, and discharge them to Rio Grande a few miles above the Lobatos gaging station. The water thus added to the river would enter below all irrigation diversions in Colorado but would become available for diversions in New Mexico. In the Rio Grande Compact concluded in 1929, construction of the sump drain is advocated as a desirable feature in the economic development and conservation of the waters of the Upper Rio Grande Basin and as a helpful factor in the reaching of a permanent compact and accord among the three signatory States.

Various estimates of the average amount of water that would be added to Rio Grande annually by the sump drain have been made from time to time, beginning with the estimate of 300,000 acre-feet by Stannard and Miller of the Bureau of Reclamation and Department of Agriculture 1915. R. I. Meeker, engineering consultant for Colorado, estimated from 175,000 to 200,000 acre-feet in data presented at the Rio Grande compact meeting in Santa Fe, January 1929; and Debler, Fowler, and Stout, a committee of engineers appointed to report to the Federal Emergency Administration of Public Works in connection with an application filed for construction of the sump drain as a project of that agency, estimated 40,000 acre-feet in 1935.

As outlined in the Debler, Fowler, Stout report, the drain would follow quite closely the trough of the basin. It would drain the numerous shallow lakes which collect there during the wet season and serve to lower the water table by as much as 5 feet adjacent to the drain and stream channels. This would permit the flow of many of the streams now seeping the area to be carried to the sump as surface flow, and eliminate as well the present seeped condition which is responsible for the losses by evaporation and transpiration. Above Head Lake the development would comprise a storm-water channel with a depth of about 5 feet. Head and San Luis Lakes would serve as regulating basins to permit the temporary storage of possible flood flows either from San Luis Creek or the east side streams, and permit of a smaller drain capacity between the lakes and Rio Grande. The drain would cross the closed basin barrier in a deep cut and join Rio Grande at Hanson Bluff about 3 miles above the mouth of Trinchera Creek.

Sources of drainage recovery.—Reliance can probably be placed upon two sources only as a water supply available to the sump drain. One, the smaller, is the contribution from the west by the ditches and drains carrying waste and return flow from the area irrigated by diversion from Rio Grande, and the other, the main source, is the flow from the eastern streams which drain the western slope of the Sangre de Cristo Range. On the north, the areas along Saguache and San Luis Creeks are at present seeped. Practically all water reaching the sump area from these creeks is used in irrigation of large meadows in the northern part of the area. In all probability any recovery of water from these seeped areas would, in keeping with present practice, be rediverted for irrigation, and is, therefore, hardly to be counted upon for any contribution to the sump drain.

In 1936, as a part of the Rio Grande joint investigation, the Geological Survey made weekly measurements of all ditches and drains crossing the road running north from Alamosa on the section line 2 miles west of the line between ranges 10 and 11 east, during the period June 25 to November 28. The total discharge for the period June 22 to November 30 of 39 ditches and one drain entering the sump area across this line of measurement is estimated to have been about 10,000 acre-feet. A portion of this is used for irrigation east of the line of measurement but most of it is lost by evaporation and by transpiration by brush. Based on these measurements for the 6 months of record, it is considered that a contribution to the sump drain, after irrigation requirements in the sump area have been met, of 10,000 acre-

feet per year from the irrigated acreage of the closed basin that is served from the Rio Grande may be conservatively assumed.

The water available to the sump drain from the eastern streams is represented by the possible saving of the water from these streams now seeping the sump lands, after the demands for irrigation have been met. The sump areas of native vegetation fed by eastern streams are about a third in grass and two-thirds in brush, with a consumptive use including precipitation as taken from the data of the Bureau of Agricultural Engineering (table 76) of about 1.2 acre-feet per acre per year. Precipitation in this part of the valley averages between 8 and 9 inches per year. About 0.4 of the demand of the native vegetation is thus being supplied from ground water sustained by the seepage and overflow of the streams. The extent to which this supply can be reduced by construction of the sump drain depends upon the depth of the drain and lateral system, if any, and its general effectiveness in lowering the water table. This remains at this juncture more or less a matter of conjecture. In the subsequent analysis assumption is made of savings of 75 percent of the present depletion by native vegetation, including grass and brush but not trees or bosque. Trees or bosque, being adjacent to the streams, would probably continue to obtain water as at present. It seems likely that this percentage would represent an upper limit for the savings.

In Appendix B, which gives the details of the estimates of water production from run-off as summarized in the section of this report on water supply, the run-off, at the foothill line, of the eastern streams of the closed basin was estimated by dividing them into three groups. Group A was taken to include those tributary to San Luis Creek from the Villa Grove gaging station to and including San Isabel Creek; group B those from North Crestone Creek to Deadman Creek, inclusive; and group C the remaining creeks to the southern boundary of the closed basin. The mean annual run-off of group A was estimated to be 30,000 acre-feet; group B, 32,700 acre-feet; and group C, 38,000 acre-feet. The southern streams of group C, Medano, Zapato, and Urraca Creeks, enter a much wider valley area than do the northern streams, and there are a few well-developed ditch systems in this section that serve extensive tracts. It is doubtful whether these streams would contribute anything to the sump drain. Hence, in estimating the flow of the eastern streams available to the drain, half only of group C run-off was taken, making the total estimated mean annual run-off at the foothill line 81,700 acre-feet.

As described in the ground-water report of the Geological Survey, Part II, the streams of San Luis Valley are, below the foothill line, subject to percolation losses to both the shallow ground water and the artesian aquifers underlying the valley. These losses occur as the streams pass over the porous alluvial fans below the mouth of the canyons. No adequate measurements of the stream losses of this character are available, but as some indication of their magnitude in the case of the eastern streams, comparison was made of the records of discharge at two gaging stations maintained on Trinchera Creek above Mountain Home Reservoir. The upper station is at Turner's Ranch and the lower just above the reservoir. The records are available only for the months April to November of each year and for the period 1923 to 1936. In this period and for these months they show a mean loss between the stations of 3,600 acre-feet. The mean run-off at the upper station for the same months of this period was 15,500 acre-feet. Between the stations there is a large hay ranch, of which perhaps 1,200 to 1,500 acres are irrigated. The consumptive use by native hay lands in this district is assumed by the Bureau of Agricultural Engineering at 1.5 acre-feet per acre. Precipitation amounts to about 10 inches per year, which gives a stream-flow depletion of about 0.7 acre-foot per acre. For 1,500 acres this would be only 1,000 acre-feet per year, which leaves 2,600 acre-feet of the loss between stations unaccounted for. By prodigal use of water so that evaporation losses would be increased, this depletion might amount to considerably more than 1,000 acre-feet, but hardly enough more but that the loss to be attributed to deep percolation would be less than 10 percent of the flow at the upper station. Lacking further data and based upon this comparison, percolation losses to the artesian aquifers from the eastern streams was assumed at 10 percent of the run-off at the foothill line, thus reducing the estimated inflow of these streams to the sump area from 81,700 acre-feet to 73,500 acre-feet.

Using the Bureau of Agricultural Engineering estimates of unit consumptive use (table 76), and the irrigated and water-consuming acreages in the consumptive area supplied by the eastern streams (considered to be all in Saguache County) as given in table A of Part III, and correcting for precipitation, the sump depletion of the inflow of the eastern streams was derived as shown in table 105. The close agreement between the indicated total depletion of 72,300 acre-feet and the inflow as estimated in the previous paragraph affords some confirmation of the correctness of the latter estimate since, at present, this inflow is entirely consumed.

Estimated recovery by sump drain.—Using the data of the preceding paragraphs, the recovery by the sump drain was estimated on the basis that it would recover 75 percent of the ground water fed by eastern streams now consumed by the evapo-transpiration of grass and brush areas and 75 percent of the pooled water surface losses. The estimate follows.

	Acre-feet	
	Losses	Inflow
[illegible]		81,700
[illegible]	8,200	
[illegible]	37,200	
[illegible]		10,000
Total	45,400	91,700
Net recovery to drain		46,300

TABLE 106.—*Estimated water consumption in the area*[1] *supplied by eastern streams of the closed basin, San Luis Valley*

Classification	Acreage	Consumptive use per year		Mean annual precipitation on the area (acre-feet)	Annual stream-flow depletion (acre-feet)
		Acre-feet per acre	Total acre-feet		
(1)	(2)	(3)	(4)	(5)	(6)
Irrigated	30,504	1.52	46,400	21,400	25,000
Native vegetation:					
Grass	32,793	1.0	32,800	23,000	9,800
Brush	57,058	1.3	74,200	40,000	34,200
Bosque trees	113	3.8	400	100	300
Total native vegetation	89,964	[2]1.19	107,400	63,100	44,300
Water surfaces	1,002	3.5	3,500	700	2,800
Miscellaneous[3]	5,318	.73	3,900	3,700	200
Total	126,788	[2]1.28	161,200	88,900	72,300

[1] Taken as the area supplied by those streams which would contribute to the proposed sump drain and considered to be all in Saguache County.
[2] Computed weighted mean of a number of classifications.
[3] Includes bare lands, village areas, and lands temporarily out of cropping.

Columns 2 and 3: From data of the Bureau of Agricultural Engineering as given in table A of part III and table 76.
Column 5: Average mean annual precipitation taken as 0.7 foot.

As previously stated, the estimated saving of 75 percent as used in the above analysis should probably be considered as an upper limit. In view of this, and the uncertainties which manifestly enter into this derivation, it seemed best to adopt a round figure of 40,000 acre-feet as the estimate of average recovery to be anticipated.

In addition to this average annual recovery by the sump drain of 40,000 acre-feet, there is the possible recovery of flood waters from San Luis and Saguache Creeks for which no allowance was made in the analysis. There would probably be some accretion also from drainage of sump lands adjacent to the drain in Alamosa County, not accounted for in the estimate of 10,000 acre-feet from the west side.

In the event of construction of the sump drain, it is likely that the present drainage systems in the closed basin would be extended and that ultimately the main drain would be extended beyond the limits now proposed. Much of the drainage water would be rediverted, so that even with a greatly expanded drainage system it is doubtful if the total discharge to Rio Grande of the sump drain would much exceed the foregoing estimate of 40,000 acre-feet per year.

In the earlier years following construction of a sump drain the yield undoubtedly would be greater until the accumulated water in soil storage had been withdrawn, which might take several seasons.

There are few data upon which to base an estimate of the monthly distribution of the sump drain flow. Since the chief source would be the salvaged flow of the eastern streams, the monthly distribution of the drain flow would very likely be quite similar in character to that of the stream flow. There would be some modification due to the smaller amounts of drainage and waste coming in from the west with a distribution of different character. Taking these considerations into account and using available stream and drainage records, a possible distribution was derived as shown in table 107.

Quality of sump drain water.—In the quality of water investigations, the data of which are summarized in a previous section and reported in detail in Part IV, analyses were made of water samples taken in 1936 from the streams and drains tributary to the sump area, from ground water in this area, and from San Luis Lake. With respect to the salinity of the stream flow, the interpretive report of the Bureau of Plant Industry states:

> Water samples have been taken from six of the streams that discharge into the northern part of the valley from the Sangre de Cristo Mountains on the east, from Crestone to Sand Creek.
>
> The conductance of these is very low, ranging from 4.6 to 10.4. The dissolved constituents are chiefly silica and calcium bicarbonate, so that these waters probably contribute very little salinity to the valley lands. Of the streams entering the northern part of the valley from the west, four have been sampled, from Kerber to La Garita Creeks. The conductances of these samples range higher than those from the streams on the east, from 9.1 to 64.1 with the highest conductance found in Kerber Creek. Detailed analysis of samples from Saguache and Carnero Creeks show that here also the chief dissolved constituents are silica and calcium bicarbonate. These findings indicate that currently the streams discharging into the northern part of the San Luis Valley are contributing very little potential salinity to the valley lands.

TABLE 107.—*Estimated total and possible monthly distribution of annual yield of proposed sump drain, San Luis Valley, Colo.*

Month	Monthly distribution	
	Percent	Acre-feet
January	3	1,200
February	[illegible]	2,000
March	[illegible]	[illegible]
April	8	[illegible]
May	10	4,000
June	15	[illegible]
July	[illegible]	[illegible]
August	[illegible]	[illegible]
September	9	3,600
October	[illegible]	2,800
November	[illegible]	[illegible]
December	3	[illegible]
Year	[illegible]	[illegible]

The same report comments also on the drainage salinity and that of San Luis Lake as follows:

> Samples from two stations on the Rio Grande Drain show conductances ranging from 27.5 to 56.9. The area north of Center is served by the Gibson Drain, which has been sampled at two stations where the conductances ranged from 29.6 to 36.6. The area lying to the east of Center, toward the valley trough, is served by the San Luis Valley Irrigation District Drain which discharges into San Luis Lake. This drainage system has been sampled at six stations with conductances ranging from 39.3 to 67.8. Samples have been taken also from two stations on San Luis Lake where conductances ranging from 63.9 to 108 were found. Detailed analyses of samples from the lake show that the chief salt constituents are sodium and magnesium combined with bicarbonate, sulphate, and chloride.

The report of analytical data gives the results of conductance tests in 1936 on water samples from 43 shallow wells in townships 40 and 41 north, range 11 east, which include San Luis and Head Lakes and a portion of the sump area west and north of the lakes which would contribute to the sump drain. These tests show a range in conductance from about 30 to as high as 800, with a rough average of about 170. The wells showing some of the higher conductances are close to San Luis Lake, although, as noted above, the conductances of the lake water itself, as sampled in 1936, did not exceed 108. Detailed analyses made of samples from 6 of the 43 wells, with an average conductance of 166, show averages of 1.55 tons of salts per acre-foot, sodium and chloride percentages of 87 and 6, respectively, relatively high amounts of bicarbonates, and low amounts of calcium, magnesium, and sulphates.

Presumably the salinity of the sump drain waters would at first be largely of the same character as that of the present shallow ground water in the vicinity. Based on the average of 1.55 tons of salts per acre-foot as given above, this means that the estimated 40,000 acre-feet flow of the drain would carry into Rio Grande annually about 60,000 tons of salts with a markedly unfavorable preponderance of sodium combinations in its constituent parts. Table 52 of the section of this report on quality of water indicates that in the period 1931 to 1936 an average of 638,000 tons of salt was carried past El Paso annually in Rio Grande. The probable maximum inflow of 60,000 tons of salt annually from the sump drain represents, then, 9 percent of the salt carried past El Paso. This does not mean, however, that there would be an increase of 9 percent in the salt content at El Paso, since part of the salts from the drain would inevitably accumulate in the Middle Valley.

It is to be anticipated that in time the drain water would become fresher, with the salinity diminishing to a content more nearly approaching that of the surface and drain waters entering the sump. From the concentrations indicated for the latter by the 1936 investigation, this might mean a reduction in the concentration of the drain flow to 1 ton of salt per acre-foot or lower, with a corresponding improvement in the salt constituents characterized by lower sodium and higher calcium percentages.

PART I

SECTION 7.—AVAILABILITY AND USE OF WATER UNDER GIVEN CONDITIONS

Previous sections of this report have established the available water supply in the Upper Rio Grande Basin; the uses and requirements for water, including estimates of the required diversion demand of the major units of the basin; the opportunities for water storage; and the possibilities of additional water supplies by transmountain diversion and by salvage of present losses. Using the data thus developed, it remains to determine the effect upon, and conditions of water supply and use in, the San Luis, Middle, and Elephant Butte-Fort Quitman sections, for the various possible combinations of draft, storage development, transmountain diversion, and salvage involved in a solution of the water problems of the Upper Rio Grande Basin; and to compare the conditions so determined with those of the past and the present. Accordingly, this section presents the results of analyses of a number of given sets of conditions as listed in table 108, and as outlined in more detail in the following paragraphs:

Various Given Conditions

Condition No. 1

Present storage capacity above Rio Grande area of San Luis Valley	acre-feet	130, 000
Diversion demand on the Rio Grande in San Luis Valley	acre-feet	650, 000
Return to Rio Grande in percent of total Rio Grande diversions		16

Period of analysis, 1892–1904 and 1911–35.

TABLE 108.—*Various given conditions for which analyses of availability and use of water are made, Upper Rio Grande Basin*

Condition number	Storage: Reservoirs	Storage: Capacity 1,000 acre-feet units	Diversion demands: Basin units	Diversion demands: 1,000 acre-feet units	Other conditions	Period of analysis	Determination of—
1	Present San Luis Valley	[4] 130	Rio Grande area—San Luis Valley.	[2] 650	Return flow to Rio Grande 16 percent of diversions.	1911-35	Effect on San Luis Valley and Lobatos.
2	Present San Luis Valley	[4] 130	San Luis Valley	[3]	Present conditions in San Luis Valley.	1892-1904 1911-35	Effect on Middle Valley, San Marcial, and Rio Grande project.
	El Vado	198	Middle Valley	580			
	Elephant Butte	2, 274	Rio Grande project and Mexico.	773			
3	Present San Luis Valley.	[4] 100	Rio Grande area—San Luis Valley.	650	Return flow to Rio Grande 16 percent of diversions.	1911-35	Effect on San Luis Valley and Lobatos.
	Vega-Sylvestre	240					
4	Present San Luis Valley.	100	Rio Grande area—San Luis Valley.	650	Return to Rio Grande in San Luis Valley 16 percent of diversions.	1892-1904 1911-35	Effect on San Luis Valley, Lobatos, Middle Valley, San Marcial, and Rio Grande project.
	Wagon Wheel Gap	1, 000	Middle Valley	580			
	El Vado	198	Rio Grande project and Mexico.	773			
	Elephant Butte	2, 274					
5	Present San Luis Valley.	100	Rio Grande area—San Luis Valley.	650	Return to Rio Grande in San Luis Valley 8 percent of diversions.	1892-1904 1911-35	Effect on Lobatos, Middle Valley, San Marcial, and Rio Grande project.
	Wagon Wheel Gap	1, 000	Middle Valley	580			
	El Vado	198	Rio Grande project and Mexico.	773			
	Elephant Butte	2, 274					
6	Conejos	162	Conejos area—San Luis Valley	230	Return flow 35 percent of diversions.	1911-35	Effect on Conejos area.
7	Present San Luis Valley.	100	Rio Grande area—San Luis Valley.	650	Return to Rio Grande in San Luis Valley 16 percent of diversions. Conejos return, 35 percent.	1911-35	Effect on Lobatos, Middle Valley, and San Marcial.
	Wagon Wheel Gap	1, 000	Conejos area—San Luis Valley.	230			
	Conejos	162	Middle Valley	580			
	El Vado	198					
8	Present San Luis Valley.	100	Rio Grande area—San Luis Valley.	750	No increase in total return flow over that with 650,000 demand.	1911-35	Effect on Rio Grande area in San Luis Valley.
	Wagon Wheel Gap	1, 000					
	Vega-Sylvestre	240					
9	Conejos	162	Conejos area—San Luis Valley	[illegible]	No increase in total return flow over that with 230,000 demand.	1911-35	Effect on Conejos area.
10	Present San Luis Valley.	100	Rio Grande area—San Luis Valley.	[5] 750	No increase in total return flow in San Luis Valley over that with 650,000 and 230,000 demands.	1911-35	Effect on Lobatos, Middle Valley, San Marcial, and Rio Grande project.
	Wagon Wheel Gap	1, 000	Conejos area—San Luis Valley	[illegible]			
	Vega-Sylvestre	240	Middle Valley	580			
	Conejos	162	Rio Grande project and Mexico.	773			
	El Vado	198					
	Elephant Butte	2, 274					
11	Present San Luis Valley.	100	Rio Grande area—San Luis Valley.	650	Return to Rio Grande in San Luis Valley 8 percent of diversions. Sump drain annual discharge to Rio Grande of 40,000 acre-feet.	1892-1904 1911-35	Effect on Lobatos, Middle Valley, San Marcial, and Rio Grande project.
	Wagon Wheel Gap	1, 000	Middle Valley	580			
	State line	[illegible]	Rio Grande project and Mexico.	773			
	El Vado	198					
	Elephant Butte	2, 274					

[1] [illegible]
[2] Ideal monthly distribution.
[3] Lobatos flow depleted for present conditions as in table 18.
[4] 100,000 acre-feet considered effective.
[5] Maximum possible development.

This analysis is to show the effect on the water supply of the area now served from Rio Grande in San Luis Valley of any attempt, with the present limited storage capacity, to divert water in accordance with an ideal irrigation demand rather than to take it, as at present available. In this analysis and the subsequent analyses for other conditions, the periods used were 1892–1904 and 1911–35. In order to determine the effect on Lobatos of given conditions above Alamosa, the change at Alamosa was applied to past Lobatos flow. The record of past flow at Alamosa, needed to derive the changes at that station, does not go back of 1912. Without using estimated flow, this limited the period of analysis to 1912–35. Because 1911 was a year of high run-off and, in all operation studies, reservoirs could safely be assumed to have filled, the period 1911–35 was adopted and estimated Alamosa flow used prior to June 1912. Although the period 1911–35 includes two severe drought years, 1931 and 1934, there were probably more critical years in the period 1892–1904, particularly the succession of dry years 1899, 1900, 1901, 1902, and 1904. It was important, therefore, that some estimate, at least, be derived of the effects of the various assumed sets of conditions, in this earlier critical period. Such estimates were derived in the various analyses but it is to be noted that with respect to effects on Lobatos flow and the Middle and Elephant Butte-Fort Quitman sections, they are based on the use of an estimated monthly flow at Alamosa as given in table 130 of Appendix A. Earliest available stream-flow records indicate that reservoirs may be safely assumed to have filled at the beginning of the 1892–1904 period and this assumption was made in the operation studies.

Condition No. 2

Present storage capacity above Rio Grande area of San Luis Valley ______ acre-feet __	[illegible]
Present storage capacity allotted Middle Valley in El Vado Reservoir ______ acre-feet __	198, 000
Present storage capacity allotted Rio Grande project in Elephant Butte Reservoir ______ acre-feet __	2, 274, 000
Present conditions of diversions and irrigation in San Luis Valley.	
Diversion demand for Middle Rio Grande Conservancy district ______ acre-feet __	580, 000
Diversion demand on Elephant Butte Reservoir for Rio Grande project and Mexican treaty obligation acre-feet __	[illegible]

Period of analysis, 1892–1904 and 1911–35.

This analysis is to show the effect upon the water supply of the Middle and Elephant Butte-Fort Quitman sections of present irrigation development in San Luis Valley, with diversions to Middle Rio Grande Conservancy District and Rio Grande Project in accordance with the adopted demands. In this and all other analyses annual evaporation from El Vado Reservoir was taken as 3.5 feet, or 2.0 feet deducting precipitation, and that from Elephant Butte Reservoir as 6.0 feet (refer to table 25), or 5.2 feet deducting precipitation. A seepage allowance of 5,000 acre-feet per month was used for Elephant Butte Reservoir and a monthly distribution of the arroyo inflow to it was estimated from the annual data of table 202 in Appendix B.

Condition No. 3

Present effective storage capacity above Rio Grande area of San Luis Valley ______ acre-feet __	100, 000
Vega-Sylvestre Reservoir ______ do ____	240, 000
Diversion demand on the Rio Grande in San Luis Valley acre-feet __	650, 000
Return to Rio Grande in percent of total Rio Grande diversions ______	16

Period of analysis, 1911–35.

This analysis is to show the effect on the water supply of the San Luis Valley area served by Rio Grande, and on the flow at Lobatos of operation of Vega-Sylvestre Reservoir. The analysis was not continued to determine the effect on Middle Valley and Elephant Butte-Fort Quitman sections as the resulting mean annual flow at Lobatos was very nearly the same as that resulting from operation of Wagon Wheel Gap Reservoir, Condition No. 4, for which complete analysis was made. For simplicity of analysis the storage of present reservoirs was considered as combined with that of Vega-Sylvestre (and with Wagon Wheel Gap in subsequent studies). The present smaller reservoirs might not fill in the same proportion as the larger ones and allowance was made for this by taking the effective capacity of present reservoirs at 100,000 acre-feet. Annual evaporation from Vega-Sylvestre Reservoir (and Wagon Wheel Gap also) was taken at 1.9 feet, or 0.6 foot deducting precipitation.

Condition No. 4

Present effective storage capacity above Rio Grande area of San Luis Valley ______ acre-feet __	100, 000
Wagon Wheel Gap Reservoir ______ do ____	[illegible]
Present capacity El Vado Reservoir ______ do ____	198, 000
Present capacity Elephant Butte Reservoir __ do ____	2, 274, 000
Diversion demand on Rio Grande in San Luis Valley acre-feet __	650, 000
Diversion demand for Middle Rio Grande Conservancy District ______ acre-feet __	580, 000
Diversion demand on Elephant Butte Reservoir for Rio Grande project and Mexican treaty obligation acre-feet __	773, 000
Return to Rio Grande in San Luis Valley in percent of total Rio Grande diversions	16

Period of analysis: effect on Middle Valley, 1892–1904 and 1911–35; effect on Rio Grande Project, 1892–1904.

This analysis is to show the effect on the water supply of the three sections of the basin, of operation of Wagon Wheel Gap Reservoir with diversions to the major units of the three sections in accordance with the adopted

demands. The effect on Rio Grande Project for the period 1911–35 was not analyzed as the resulting mean annual flow at San Marcial was practically the same as given under Condition No. 2.

Condition No. 5

The items of this condition are exactly the same as for Condition No. 4, except that the return flow to Rio Grande in San Luis Valley is taken as 8 percent only of the total Rio Grande diversions in the valley. Although, as described in the development of the diversion demand for the Rio Grande area of San Luis Valley, the return flow has averaged better than 16 percent in the 3 years 1934, 1935, and 1936, and this amount of return is considered to represent very conservatively that to be anticipated in the future, there are a number of years in the period previous to 1934 for which data are available, when the return, as indicated by table 36, was less than 16 percent. The average for the period 1928 to 1936, inclusive, for the return above Alamosa is 7.6 percent of total diversions above Alamosa. Because this return flow is such an important item in the water available to lower sections, and because the allowance for it constitutes one of the fundamental assumptions of the analyses, a return of 8 percent as a minimum remotely possible but not probable was used in certain of the analyses.

Condition No. 6

Reservoir capacity on the Conejos River ... acre-feet	162,000
Diversion demand on Conejos River ... do	230,000
Return flow to Conejos in percent of Conejos diversions	35
Period of analysis, 1911–35.	

This analysis is to show the effect on the water supply of the Conejos area and consequently on that of Rio Grande, of storage regulation, and diversions in accordance with an ideal irrigation demand. This effect is combined with that of Wagon Wheel Gap development as shown under Condition No. 7. In the previous description of investigations of proposed storage projects it was indicated that the Conejos investigations were not yet complete. Hence, final data on storage possibilities were not available for this analysis. The assumption was made that a reservoir of at least 100,000 acre-feet capacity would be found feasible on the lower river, and to this was added the capacity of the upper Conejos Reservoir No. 6, 32,000 acre-feet, and the Mogote off-stream reservoir tentatively estimated at 30,000 acre-feet capacity. For simplicity of the operation study, all three were considered as one reservoir located at the Mogote gaging station. Evaporation was taken at 2.0 feet, or 1.4 feet deducting precipitation. No analysis could be made for the early period 1892–1904 because of the lack of records.

Condition No. 7

Present effective storage capacity above Rio Grande area of San Luis Valley ... acre-feet	100,000
Wagon Wheel Gap Reservoir ... do	1,000,000
Conejos Reservoirs ... do	162,000
El Vado Reservoir ... do	198,000
Diversion demand on Rio Grande in San Luis Valley ... acre-feet	650,000
Diversion demand on Conejos in San Luis Valley ... acre-feet	230,000
Diversion demand for Middle Rio Grande Conservancy District ... acre-feet	580,000
Return to Rio Grande in San Luis Valley in percent of total Rio Grande diversions	16
Return to Conejos in percent of diversions	35
Period of analysis, 1911–35.	

This analysis is to show the effect on the flow at Lobatos and on the water supply of the Middle section, of the combined operation of Wagon Wheel Gap and Conejos Reservoirs with diversions to the major units of San Luis and Middle sections in accordance with the adopted demands. The effect of this combination on the Rio Grande Project was not analyzed as the resulting mean annual flow at San Marcial was very nearly the same as that given by the analysis under Condition No. 2.

Condition No. 8

Present effective storage capacity above Rio Grande area of San Luis Valley ... acre-feet	100,000
Wagon Wheel Gap Reservoir ... do	1,000,000
Vega-Sylvestre Reservoir ... do	240,000
Diversion demand on Rio Grande in San Luis Valley ... acre-feet	750,000
Return to Rio Grande the same as for Condition No. 4; i. e., 16 percent of 650,000 acre-feet.	
Period of analysis, 1911–35.	

This analysis is to show the effect on the water supply of the Rio Grande area in San Luis Valley of the combined storage of Wagon Wheel Gap and Vega-Sylvestre Reservoirs and a diversion demand estimated to represent the maximum possible development. The mean annual run-off of Rio Grande near Del Norte in the period 1911–35 was 755,000 acre-feet. Allowing 5,000 acre-feet for reservoir evaporation, the maximum diversion demand for the normal year was taken at 750,000 acre-feet. Under this condition it was hypothecated that no restrictions whatever be placed upon development in San Luis Valley. Since the extension of development would, of necessity, be principally in the closed basin area, no reliance could be placed on any more return flow to Rio Grande than in the case of the 650,000 acre-feet diversion demand. Although both Wagon Wheel Gap and Vega-Sylvestre Reservoirs were used, because of the drought period ending in 1904, only 1,000,000 acre-feet storage was assumed to be on hand at the beginning of the 1911–35 period.

Condition No. 9

Reservoir capacity on Conejos River .... acre-feet ..	162,000
Diversion Demand on the Conejos River .... do	300,000
Return to Conejos the same as for Condition No. 6; i. e., 35-percent of 230,000 acre-feet.	
Period of analysis, 1911–35.	

This analysis is to show the effect on the water supply of the Conejos area of the same storage regulation as under Condition No. 6 (probably about the maximum as limited by physical conditions) but with a diversion demand estimated to represent the maximum possible development. It would be necessary that the increased diversions be made up by utilization of reservoir spills and the supply that cannot be diverted by present canals. This increase was estimated at 70,000 acre-feet, which, added to the demand of Condition No. 6, gave 300,000 acre-feet. The 1936 survey of irrigated and other water-consuming areas indicates but little opportunity for increased depletion on the Conejos proper, and it was assumed that the expansion of irrigated acreage implied by the maximum demand would be principally to irrigable lands south of Antonito in New Mexico. In this case any more return flow to the Conejos than with the 230,000 acre-feet demand would be doubtful, and no more was assumed in the analysis. Records were not available to extend this analysis to the earlier critical period, 1892–1904.

Condition No. 10

Present effective storage capacity above Rio Grande area of San Luis Valley .... acre-feet ..	100,000
Wagon Wheel Gap Reservoir .... do	1,000,000
Vega-Sylvestre Reservoir .... do	240,000
Conejos Reservoirs .... do	162,000
El Vado Reservoir .... do	198,000
Elephant Butte Reservoir .... do	1,274,000
Diversion demand on Rio Grande in San Louis Valley .... do	750,000
Diversion demand on Conejos in San Luis Valley do	300,000
Diversion demand for Middle Rio Grande Conservancy District .... do	580,000
Diversion demand on Elephant Butte Reservoir for Rio Grande project and Mexican treaty obligation .... do	773,000
Return to Rio Grande and Conejos in San Luis Valley the same as for Conditions Nos. 4 and 6; i. e., 16 percent of 650,000 acre-feet, 35 percent of 230,000 acre-feet.	
Period of analysis, 1911–35.	

This analysis is to show the effect on Lobatos flow and on the water supply of Middle and Elephant Butte-Fort Quitman sections, of unrestricted and maximum possible development in the Rio Grande and Conejos areas of San Luis Valley. It is for hypothecated maximum diversion demands for these areas, and the adopted diversion demands for Middle Rio Grande Conservancy District, Rio Grande project and Mexico, and represents the combined effect of Conditions Nos. 8 and 9.

Condition No. 11

Present effective storage capacity above Rio Grande area in San Luis Valley .... acre-feet ..	100,000
Wagon Wheel Gap Reservoir .... do	1,000,000
State Line Reservoir .... do	460,000
El Vado Reservoir .... do	198,000
Elephant Butte Reservoir .... do	2,274,000
Diversion demand on Rio Grande in San Luis Valley do	650,000
Diversion demand for Middle Rio Grande Conservancy District .... do	580,000
Diversion demand on Elephant Butte Reservoir for Rio Grande project and Mexican treaty obligation do	773,000
Sump drain inflow to Rio Grande above Lobatos do	40,000
Return flow to Rio Grande in San Luis Valley in per cent of total Rio Grande diversions	8
Period of analysis, 1892–1904 and 1911–35.	

This analysis is to show the combined effect of operation of Wagon Wheel Gap Reservoir, State Line Reservoir, and the sump drain on the water supply of Middle and Elephant Butte-Fort Quitman sections, with the adopted diversion demands of the major units in these sections. The return flow to Rio Grande in San Luis Valley was taken as 8 percent of the total Rio Grande diversions in the valley, as under Condition No. 5. This was done in order to set up the most unfavorable contingency with respect to the lower sections. The operation of State Line Reservoir would be largely to eliminate shortages in the Middle section. Final data on storage capacity for it were not available but from a preliminary map of 1937 surveys a capacity of 460,000 acre-feet was indicated as probable below elevation 7,500 at the Ute Mountain dam site. Annual evaporation was taken as 3.7 feet, or 3.2 feet deducting precipitation.

Results of Analyses

The results of the analyses under Conditions Nos. 1 to 11 and comparisons between their effects are most readily presented by summarizations for each condition of (1) annual run-off of Rio Grande at Lobatos and San Marcial and of Conejos River at mouth; (2) monthly run-off at Lobatos for maximum, minimum, and mean years; and (3) amount and year of occurrence of shortages in San Luis, Middle, and Elephant Butte-Fort Quitman sections.

Annual Run-off at Key Stations Under Given Conditions

Tables 109, 110, and 111 show the annual run-off of Rio Grande at Lobatos and San Marcial and of Conejos River at mouth, respectively, for the years in the two periods of analysis, and for the Conditions indicated. The same data for Lobatos and San Marcial are also shown graphically by figures 40 and 41.

The effect on Rio Grande at lower stations of increased storage developments in San Luis Valley is to decrease the annual run-off in high water years by storage and to increase it during low years by release of water held over from the abundant years. It will be observed that for Condition No. 4, which includes Wagon Wheel Gap Reservoir and the adopted diversion demands in all sections, there is no decrease in the mean annual flow from that under Condition No. 2, which represents present development in San Luis Valley, neither at Lobatos nor at San Marcial, but rather a small increase. For the hypothecated Conditions Nos. 5 and 10, substantial reductions in the mean annual flow at these two stations are indicated.

TABLE 109.—*Annual run-off of Rio Grande near Lobatos under various given conditions of storage and irrigation draft*

[Unit 1,000 acre-feet]

Year	Condition number[1]							
	1	2	3	4	5	7	10	11
1892		371.0		438.2	386.2			426.2
1893		260.0		329.3	277.3			317.3
1894		200.0		257.7	205.7			245.7
1895		389.0		455.1	403.1			443.1
1896		237.0		273.7	223.6			263.6
1897		617.0		501.0	449.0			489.0
1898		430.0		431.0	379.0			419.0
1899		174.3		203.2	159.0			199.0
1900		255.8		287.6	250.0			290.0
1901		241.7		283.7	245.3			285.3
1902		109.7		127.9	105.0			145.0
1903		447.0		388.4	336.4			376.1
1904		277.6		183.8	149.7			189.7
13-year mean		308.5		320.0	274.6			314.6
1911	1,015.2	1,008.9	681.6	658.7	606.7	569.6	438.6	646.7
1912	768.4	627.2	727.8	721.9	669.9	788.0	516.7	709.9
1913	370.4	243.2	281.5	262.5	210.5	295.1	269.5	250.7
1914	543.8	374.4	356.6	330.3	278.3	287.4	276.3	318.3
1915	440.0	333.0	362.6	357.7	305.7	351.3	317.6	345.7
1916	794.8	697.5	580.0	610.1	558.1	592.0	351.8	598.1
1917	706.5	725.4	712.5	720.2	668.2	761.9	390.9	708.2
1918	305.6	239.2	288.6	275.7	223.7	299.7	251.0	263.7
1919	605.8	439.2	466.7	426.3	374.3	438.1	377.0	414.3
1920	987.1	863.6	827.2	870.1	818.1	823.8	462.9	858.1
1921	742.1	523.9	641.2	636.8	584.8	663.4	330.6	624.8
1922	794.3	606.9	806.2	808.2	756.2	819.7	537.9	796.2
1923	722.4	639.5	591.9	576.6	524.6	549.8	398.3	564.6
1924	786.6	565.0	771.2	783.0	731.0	811.8	578.7	771.0
1925	442.5	379.0	347.1	317.9	265.9	332.4	314.9	305.9
1926	479.9	344.7	399.8	385.8	333.8	395.1	294.9	373.8
1927	770.8	711.8	535.3	553.7	501.7	522.0	340.5	541.7
1928	426.7	270.4	422.4	434.4	382.4	494.6	313.4	422.4
1929	694.3	594.8	499.0	502.1	450.1	482.1	318.7	490.1
1930	347.6	260.4	356.3	351.1	299.1	411.5	303.1	339.1
1931	187.7	149.5	155.5	176.0	124.0	231.0	193.9	164.0
1932	780.7	561.4	592.9	528.9	476.9	426.9	385.7	516.9
1933	311.5	252.0	300.5	292.2	240.2	324.1	272.9	280.2
1934	186.8	130.8	137.8	171.7	119.7	222.9	177.5	159.7
1935	492.1	430.1	404.9	380.6	328.6	269.0	256.7	368.6
25-year mean	588.1	478.1	489.9	485.3	433.3	486.5	346.8	473.3

[1] Refer to table 108.

With the unrestricted development in San Luis Valley as represented by Condition No. 10, the reduction at Lobatos for the 25-year period is 28 percent from present conditions. At San Marcial, however, the corresponding reduction is only 13 percent.

The mean flow at Lobatos for Condition No. 1, which represents no additional storage in San Luis Valley but diversions there in accordance with the ideal demand is, of course, substantially greater than for Condition

TABLE 110.—*Annual run-off of Rio Grande at San Marcial under various given conditions of storage and irrigation draft*

[Unit 1,000 acre-feet]

Year	Condition number[1]					
	2	4	5	7	10	11
1892	1,133.4	1,158.4	1,131.3			[illegible]
1893	511.2	580.0	528.4			[illegible]
1894	396.7	447.3	403.2			415.1
1895	1,082.2	1,138.5	1,084.5			1,031.8
1896	647.1	658.7	[illegible]			[illegible]
1897	2,039.5	1,889.3	1,862.0			1,764.7
1898	884.9	893.0	831.7			[illegible]
1899	336.0	357.8	324.6			[illegible]
1900	366.8	384.0	355.2			262.0
1901	507.5	525.9	501.6			[illegible]
1902	227.8	234.8	221.3			[illegible]
1903	986.5	909.2	872.1			788.8
1904	882.4	783.7	764.3			750.8
13-year mean	769.4	766.2	732.0			692.8
1911	1,813.9	1,464.1	1,412.1	1,377.7	1,240.9	1,259.0
1912	1,506.3	1,574.8	1,543.2	1,619.2	1,347.9	1,499.0
1913	516.7	525.8	478.7	542.2	534.1	463.5
1914	892.7	884.2	807.6	878.6	850.1	[illegible]
1915	1,403.3	1,402.6	1,368.6	1,376.5	1,347.5	1,330.1
1916	1,656.4	1,594.5	1,525.1	1,595.9	1,351.5	[illegible]
1917	1,098.6	1,074.4	1,037.4	1,097.8	738.2	[illegible]
1918	386.5	409.5	368.4	419.7	359.9	350.1
1919	1,338.3	1,350.1	1,273.4	1,393.8	1,332.5	[illegible]
1920	2,307.2	2,298.9	2,261.2	2,239.0	1,878.1	2,291.2
1921	1,292.0	1,428.8	1,362.3	1,469.0	1,136.3	1,379.5
1922	1,008.9	1,176.6	1,149.5	1,159.3	877.5	1,107.2
1923	1,083.5	1,063.6	1,005.8	1,056.7	905.4	[illegible]
1924	1,392.3	1,563.7	1,518.0	1,565.6	1,332.5	[illegible]
1925	411.3	396.8	354.9	408.9	392.6	317.3
1926	1,066.7	1,081.5	1,020.4	1,094.9	993.9	1,026.0
1927	1,388.5	1,265.7	1,188.9	[illegible]	1,084.9	1,192.0
1928	675.3	807.4	780.3	829.8	648.6	726.3
1929	1,322.0	1,260.6	1,184.8	1,278.0	1,114.7	1,222.6
1930	775.0	825.3	798.2	854.9	746.5	[illegible]
1931	502.9	533.8	484.9	577.0	560.4	497.6
1932	1,328.1	1,291.8	1,242.1	1,210.0	1,148.4	1,187.7
1933	693.3	712.4	680.5	730.1	678.8	654.7
1934	303.8	313.9	312.4	328.8	328.3	266.1
1935	893.9	834.2	782.7	722.7	724.3	746.8
25-year mean	1,082.3	1,085.4	1,037.7	1,083.7	946.2	1,013.9

[1] Refer to table 108.

TABLE 111.—*Annual run-off of Conejos River at mouth under various given conditions of storage and irrigation draft*

[Unit 1,000 acre-feet]

Year	Measured[1]	Condition number[2]		Year	Measured[1]	Condition number[2]	
		6	9			6	9
1911	339.1	250.0	194.2	1925	91.3	105.8	90.3
1912	241.3	307.4	271.6	1926	185.0	194.3	94.1
1913	60.8	93.4	67.8	1927	251.6	219.9	127.8
1914	137.6	94.7	83.6	1928	109.6	169.8	113.0
1915	109.5	103.1	76.5	1929	212.1	192.1	109.7
1916	282.0	263.9	120.8	1930	119.5	179.9	120.1
1917	226.7	268.4	181.4	1931	34.2	89.2	52.1
1918	118.1	142.1	93.5	1932	308.0	206.0	165.2
1919	144.7	156.5	95.4	1933	110.9	142.8	91.6
1920	417.1	370.8	272.7	1934	20.8	72.0	45.3
1921	164.0	190.6	137.0	1935	203.0	91.4	85.1
1922	250.6	262.1	191.3				
1923	295.7	268.9	195.8	25-year mean	189.5	190.7	133.7
1924	304.1	332.9	266.3				

[1] Estimated 1911 to 1920.
[2] Refer to table 108.

No. 2, present conditions, because under the ideal demand much of the supply becomes indivertible and greater shortages result.

The only difference between Conditions Nos. 5 and 11 with respect to the effect on Lobatos flow is the addition of the sump drain yield of 40,000 acre-feet which,

of course, appears throughout in tables 109, 112, and 113. With respect to the effect on San Marcial flow, Condition No. 11 includes State Line Reservoir not included under Condition No. 5. This yields more water for the Middle Valley with a corresponding reduction for the Elephant Butte-Fort Quitman section. Hence, the mean flow at San Marcial under Condition No. 11, as shown in table 110, is less than under Condition No. 5.

As shown by table 111, the storage development on the Conejos River with the adopted diversion demand ideally distributed as under Condition No. 6 results in practically no change in the mean annual flow of Conejos River at its mouth from that of the present. Condition No. 9, the maximum possible development, results in a reduction from the measured mean flow of 29 percent.

As indicated in both tables 109 and 110, the mean annual flows for the period 1892–1904 are much lower than for the period 1911–35 and the earlier period appears to have been much the more critical of the two. Over a generation elapsed between the critical years of the two periods.

Monthly Run-off at Lobatos Under Given Conditions

Tables 112 and 113 show the monthly run-off of Rio Grande near Lobatos for minimum, mean, and maximum years of the two periods and for the Conditions indicated. These data are also shown by the graphs of figures 42 and 43. The maximum and minimum years used are those of maximum and minimum flow at the Del Norte station. It will be noted that all of the Conditions involving increased storage in the San Luis section result in an improvement over the present conditions of No. 2, in the regimen of flow at Lobatos from month to month. This is particularly noticeable in the summer and fall months of the minimum year. It represents the effect of storage in regulating the supply to a monthly distribution more in agreement with irrigation demands by reducing peaks and building up the flow during the summer months, and by holding water over from wet to dry years. The resulting improvement in return-flow distribution is directly reflected in the improved regimen at Lobatos.

Referring to table 113, in the maximum year 1911 a June run-off of 180,000 acre-feet under present conditions is reduced to 118,000 acre-feet under Condition

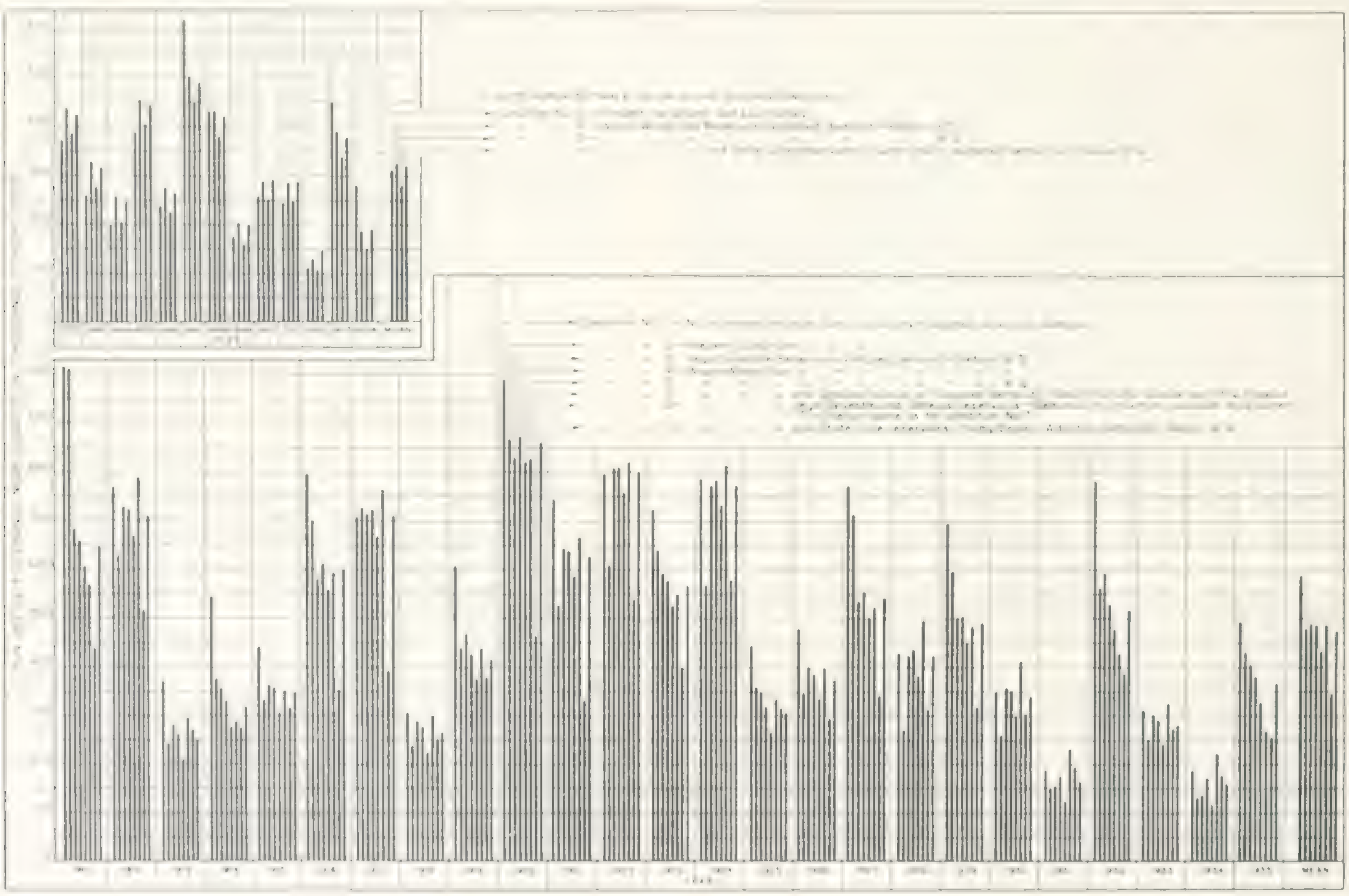


FIGURE [illegible].—Annual run-off of Rio Grande near Lobatos, Colo., under various given conditions of storage and irrigation draft.

No. 4 and to 100,000 acre-feet under the extreme Condition No. 10. In the minimum year 1934 a July run-off of 700 acre-feet under present conditions is increased to 16,500 and 23,000 acre-feet under Conditions Nos. 4 and 10, respectively. The mean year shows less striking changes, but clearly indicates the improvement in the flow of the late summer months. The data of table 112 for the earlier period, 1892–1904, show similar changes, although the improvement in the flow from May to October in the minimum year under Condition No. 5 is very slight. The improvement shown in the minimum year under Condition No. 11 is largely due to the added inflow of the sump drain. Because the same quantity was added for the latter in all years, the improvement shown is probably too high by the amount that the flow of the sump drain might have been reduced in a minimum year.

In general, the indication of the data of tables 112 and 113 is that where increased storage in San Luis Valley does not reduce the mean annual outflow at Lobatos it is equivalent to an increase in storage capacity for the Middle Valley in regulating the supply to better conform to the irrigation demands of that valley.

Because of the regulation afforded by the large storage capacity of Elephant Butte Reservoir, releases in accordance with the irrigation demand can be made independently of monthly changes in inflow to the

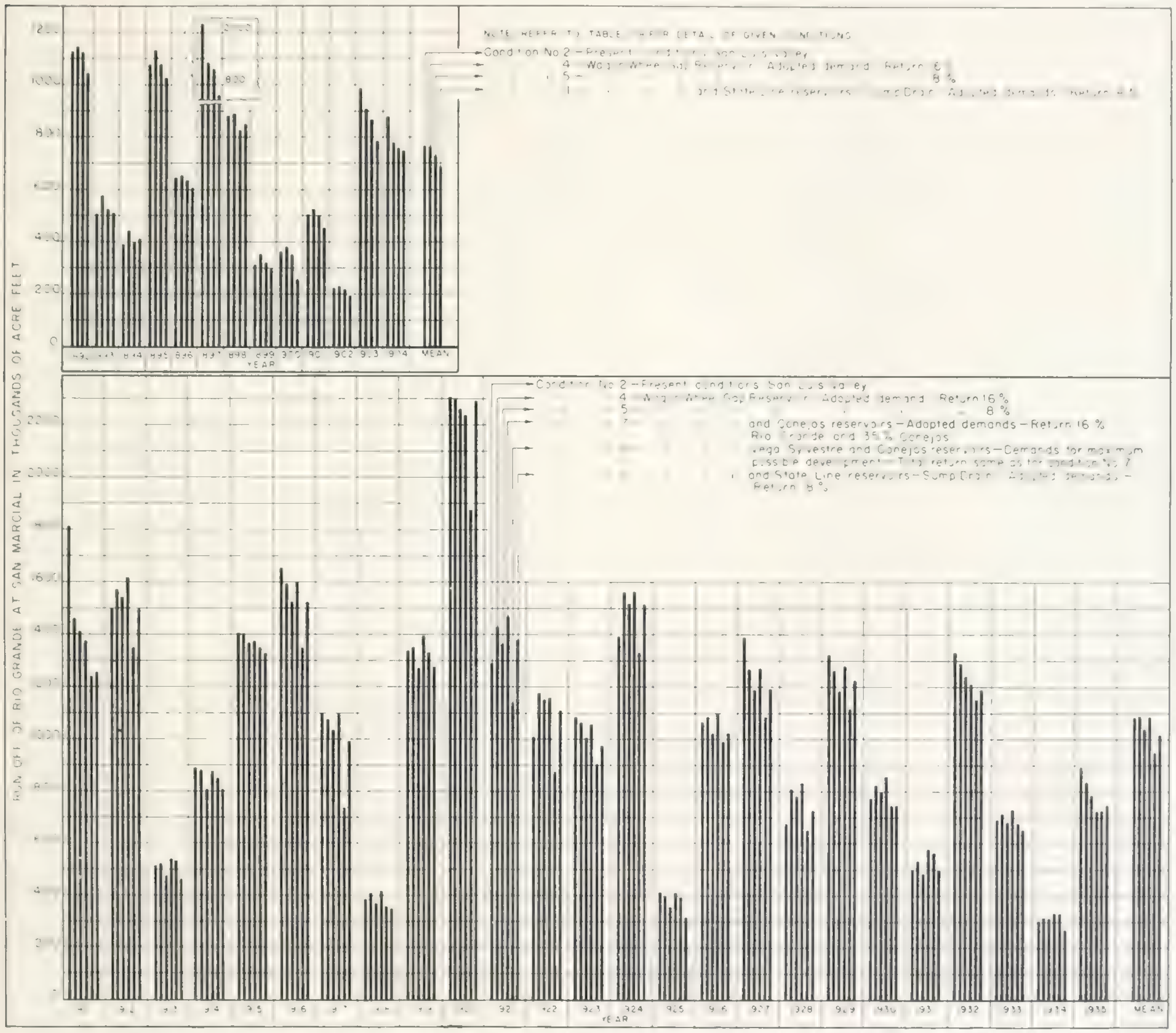


FIGURE 41.—Annual run-off of Rio Grande at San Marcial, N. Mex., under various given conditions of storage and irrigation draft

TABLE 112.—*Monthly run-off of Rio Grande near Lobatos for minimum, mean, and maximum years, 1892–1904, under various given conditions of storage and irrigation draft*

[Unit 1,000 acre-feet]

Month	Condition number [1]			
	2	[illegible]	[illegible]	[illegible]
MAXIMUM YEAR ([illegible]) [2]				
January	16.0	12.7	11.7	12.9
February	13.0	11.0	10.0	12.0
March	41.0	23.1	22.1	24.1
April	38.0	40.8	39.2	42.4
May	139.0	130.4	126.2	130.2
June	97.0	107.6	97.7	103.7
July	25.0	42.6	[illegible]	[illegible]
August	3.0	[illegible]	[illegible]	15.6
September	14.0	[illegible]	8.9	12.5
October	134.0	43.9	39.7	42.5
November	56.0	35.2	32.6	35.0
December	41.0	19.8	18.2	19.4
Year	617.0	501.0	449.0	489.0
MINIMUM YEAR ([illegible]) [3]				
January	11.1	[illegible]	11.6	12.8
February	8.9	10.0	9.0	11.0
March	18.8	17.9	[illegible]	[illegible]
April	17.3	15.1	13.5	16.7
May	[illegible]	30.9	26.7	30.7
June	3.7	9.5	[illegible]	12.4
July	0.7	0.6	0.1	6.1
August	0.6	1.1	0.3	[illegible]
September	1.0	5.1	2.8	6.4
October	5.3	[illegible]	3.4	6.2
November	9.1	[illegible]	[illegible]	10.0
December	9.7	8.3	[illegible]	7.9
Year	109.7	127.9	[illegible]	145.0
MEAN YEAR				
January	[illegible]	[illegible]	[illegible]	12.8
February	13.4	11.3	10.4	12.4
March	27.2	21.6	20.5	[illegible]
April	32.3	[illegible]	33.9	37.1
May	73.8	77.4	73.2	77.2
June	60.2	62.6	53.5	59.5
July	12.9	25.7	17.8	23.8
August	4.0	14.0	8.0	13.6
September	[illegible]	12.6	7.4	11.0
October	27.8	15.9	11.7	[illegible]
November	19.1	16.8	14.2	[illegible]
December	17.5	[illegible]	12.4	[illegible]
Year	[illegible]	[illegible]	[illegible]	[illegible]

[1] Refer to table [illegible].
[2] Year of maximum flow at Del Norte.
[3] Year of minimum flow at Del Norte.

TABLE 113.—*Monthly run-off of Rio Grande near Lobatos for minimum, mean, and maximum years, 1911 to 1935, under various given conditions of storage and irrigation draft*

[Unit 1,000 acre-feet]

Month	Condition number [1]							
	1	2	3	4	[illegible]	7	10	[illegible]
MAXIMUM YEAR (1911) [2]								
January	27.1	18.8	18.1	15.1	14.1	14.4	14.8	15.3
February	[illegible]	17.1	[illegible]	13.5	12.5	12.9	13.3	14.5
March	35.9	27.1	25.2	23.2	[illegible]	21.8	22.1	24.2
April	[illegible]	24.4	22.5	[illegible]	18.6	16.2	16.2	21.8
May	[illegible]	129.0	114.4	102.4	98.2	43.4	37.4	102.2
June	248.3	180.0	117.6	117.6	107.7	119.3	[illegible]	113.7
July	77.9	145.0	82.3	82.1	72.2	[illegible]	42.1	78.2
August	19.9	19.6	30.4	[illegible]	21.6	35.9	35.9	27.2
September	33.4	25.6	25.7	25.7	19.5	26.7	26.7	23.1
October	189.4	335.0	138.5	138.1	133.9	118.9	72.3	136.7
November	52.5	43.6	51.7	51.7	49.1	56.9	30.9	[illegible]
December	40.7	[illegible]	[illegible]	38.7	37.1	41.6	26.6	38.3
Year	1,015.2	1,008.9	681.6	[illegible]	606.7	[illegible]	[illegible]	646.7
MINIMUM YEAR ([illegible]) [3]								
January	24.3	18.0	20.7	18.7	17.7	18.8	17.5	18.9
February	22.0	21.2	19.5	17.5	16.5	[illegible]	16.8	18.5
March	29.0	27.5	22.7	[illegible]	19.7	22.1	20.9	21.7
April	44.5	27.7	[illegible]	[illegible]	8.7	11.1	11.1	11.9
May	11.2	[illegible]	11.9	11.9	7.7	17.1	17.1	11.7
June	[illegible]	[illegible]	7.9	16.4	[illegible]	31.3	30.0	12.5
July	[illegible]	[illegible]	[illegible]	16.5	[illegible]	31.4	23.0	12.6
August	1.7	[illegible]	1.5	[illegible]	[illegible]	[illegible]	2.7	12.1
September	[illegible]	1.9	6.7	12.0	5.8	13.5	5.8	9.4
October	11.2	5.0	9.8	9.8	5.6	11.3	[illegible]	8.4
November	19.7	4.7	15.0	13.4	[illegible]	15.4	14.3	13.2
December	14.2	11.4	11.3	9.2	7.6	8.4	8.4	[illegible]
Year	[illegible]	130.8	137.8	171.7	119.7	222.9	177.5	159.7
MEAN YEAR								
January	23.1	19.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17.2
February	23.3	21.2	19.4	[illegible]	17.2	[illegible]	15.8	19.2
March	33.9	[illegible]	29.0	[illegible]	25.8	[illegible]	23.2	27.8
April	41.6	28.9	31.7	31.7	30.1	29.2	21.0	[illegible]
May	148.0	102.6	115.5	[illegible]	109.3	[illegible]	48.7	[illegible]
June	137.1	113.5	120.4	125.3	[illegible]	122.8	[illegible]	121.4
July	31.6	46.6	37.3	[illegible]	[illegible]	42.2	[illegible]	[illegible]
August	18.2	15.5	24.1	25.4	[illegible]	34.9	33.0	22.2
September	27.6	[illegible]	21.2	20.3	14.1	25.6	23.8	17.7
October	43.6	35.2	26.0	25.2	21.0	26.2	21.0	[illegible]
November	33.9	[illegible]	25.6	23.8	21.2	26.9	[illegible]	[illegible]
December	26.2	25.2	21.2	19.6	[illegible]	[illegible]	[illegible]	19.2
Year	588.1	478.1	489.9	485.3	433.3	486.5	346.8	[illegible]

[1] Refer to table [illegible].
[2] Year of maximum flow at Del Norte.
[3] Year of minimum flow at Del Norte.

reservoir as measured at San Marcial. The latter are, therefore, without effect on the water supply of the Elephant Butte-Fort Quitman section except insofar as improved distribution of flow to the Middle Valley may permit of greater diversions in that section with a possible reduction in the total amount of water available to the Elephant Butte-Fort Quitman section.

Water Shortages under Given Conditions

Tables 114, 115, and 116 show the water shortages by years in the San Luis, Middle, and Elephant Butte-Fort Quitman sections under the various Conditions and for the period 1892–1904 and 1911–1935. Comment is made in the order of Condition numbers. It is to be noted that the period 1904–1911 comprises a series of wet years with run-off well above normal in most cases. For this reason, although the analyses do not cover this period, it is certain that in it no shortages would have occurred under any of the Conditions except No. 1 and possibly No. 9.

Condition No. 1.—Under this Condition shortages in the supply for the area served from Rio Grande in San Luis Valley would have occurred every year in the 25-year period 1911–35. This is due to lack of coordination between river flow and ideal distribution of the diversion demand. It clearly shows that a monthly schedule of diversions conforming to the irrigation demand cannot be practiced without regulation of the stream flow. Lacking the latter, unbalanced early season diversions must continue if advantage is to be taken of the stream flow as it occurs.

Condition No. 2.—Under present development in San Luis Valley shortages would have occurred in the Middle Valley in 6 years of the period 1892–1904 and

TABLE 114.—*Water shortages in San Luis section, Upper Rio Grande Basin, under various conditions of storage and irrigation draft*

[Unit 1,000 acre-feet]

Year	Condition number [1]					
	1	3	4	6	8	[illegible]
1892			0			
1893			0			
1894			0			
1895			0			
1896			20.1			
1897			0			
1898			0			
1899			87.1			
1900			159.6			
1901			190.7			
1902			424.6			
1903			0			
1904			285.9			
Maximum year in percent [2]			65			
1911	103.2	0	0	0	0	0
1912	170.8	0	0	0	0	0
1913	246.1	0	0	0	0	66.2
1914	104.9	0	0	0	0	18.3
1915	110.7	0	0	0	0	17.4
1916	64.1	0	0	0	0	0
1917	51.4	0	0	0	0	0
1918	208.4	0	0	0	0	0
1919	104.6	0	0	0	0	0
1920	66.8	0	0	0	0	0
1921	32.3	0	0	0	0	0
1922	86.4	0	0	0	0	0
1923	89.2	0	0	0	0	0
1924	140.3	0	0	0	0	0
1925	143.7	0	0	0	0	3.2
1926	117.3	0	0	0	0	0
1927	45.4	0	0	0	0	0
1928	149.1	0	0	0	0	0
1929	63.9	0	0	0	0	0
1930	199.7	0	0	0	0	0
1931	358.4	255.1	0	6.8	0	112.2
1932	38.7	0	0	0	0	0
1933	218.2	19.3	0	0	0	0
1934	424.1	357.3	0	36.3	141.2	151.3
1935	112.7	1.0	0	0	62.3	0
Maximum year in percent [2]	65	55	0	16	19	50

[1] Refer to table 108.
[2] Maximum shortage in percent of diversion demand.

TABLE 115.—*Water shortages in Middle section, Upper Rio Grande Basin, under various conditions of storage and irrigation draft*

[Unit 1,000 acre-feet]

Year	Condition number [1]					
	2	4	[illegible]	7	[illegible]	[illegible]
1892	0	0	0			
1893	0	0	0			
1894	51.2	0	28.1			
1895	0	0	0			0
1896	63.5	15.9	48.7			0
1897	0	0	0			0
1898	0	0	0			0
1899	16.7	0	12.7			0
1900	106.7	70.7	96.4			0
1901	0	0	0			0
1902	190.9	151.9	178.3			0
1903	0	0	0			0
1904	186.4	162.2	192.5			0
Maximum year in percent [2]	33	28	33			0
1911	0	0	0	0	0	0
1912	0	0	0	0	0	0
1913	0	0	0	0	0	0
1914	0	0	0	0	0	0
1915	0	0	0	0	0	0
1916	0	0	0	0	0	0
1917	0	0	0	0	0	0
1918	0	0	0	0	0	0
1919	0	0	0	0	0	0
1920	0	0	0	0	0	0
1921	0	0	0	0	0	0
1922	0	0	0	0	0	0
1923	0	0	0	0	0	0
1924	0	0	0	0	0	0
1925	0	0	0	0	0	0
1926	0	0	0	0	0	0
1927	0	0	0	0	0	0
1928	0	0	0	0	0	0
1929	0	0	0	0	0	0
1930	0	0	0	0	0	0
1931	25.5	0	17.1	0	0	0
1932	0	0	0	0	0	0
1933	0	0	0	0	0	0
1934	236.6	160.7	225.2	79.9	119.0	0
1935	0	0	0.1	0	0	0
Maximum year in percent [2]	41	28	39	11	20	0

[1] Refer to table 108.
[2] Maximum shortage in percent of diversion demand.

2 years of the period 1911–35. The indicated maximum shortages in the two periods are 191,000 acre-feet, or 33 percent of the diversion demand in 1902, and 237,000 acre-feet, or 41 percent, in 1934. Although these maxima are not excessive for an isolated year, the succession of shortages in the drought years in the early period represents a serious situation which could be, in part, relieved by storage.

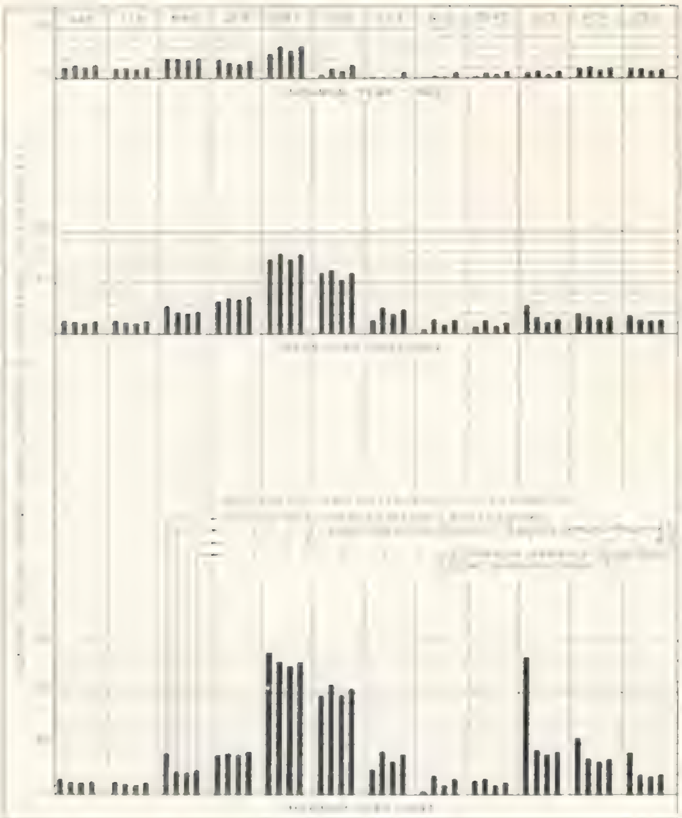
In the Elephant Butte-Fort Quitman section shortages would have occurred in 1902, 1903, and 1904 with the maximum of 383,000 acre-feet in 1904, representing 50 percent of the diversion demand. No shortages are indicated in the later period.

Condition No. 3.—Shortages in the Rio Grande area of San Luis Valley, with Vega-Sylvestre Reservoir and present storage, would have been 39 and 55 percent of the diversion demand in 1931 and 1934, respectively. These heavy shortages and the large number of reservoir spills developed in the operation study for the 1911–35 period indicate that Vega-Sylvestre Reservoir would be inadequate to regulate the supply to the adopted diversion demand.

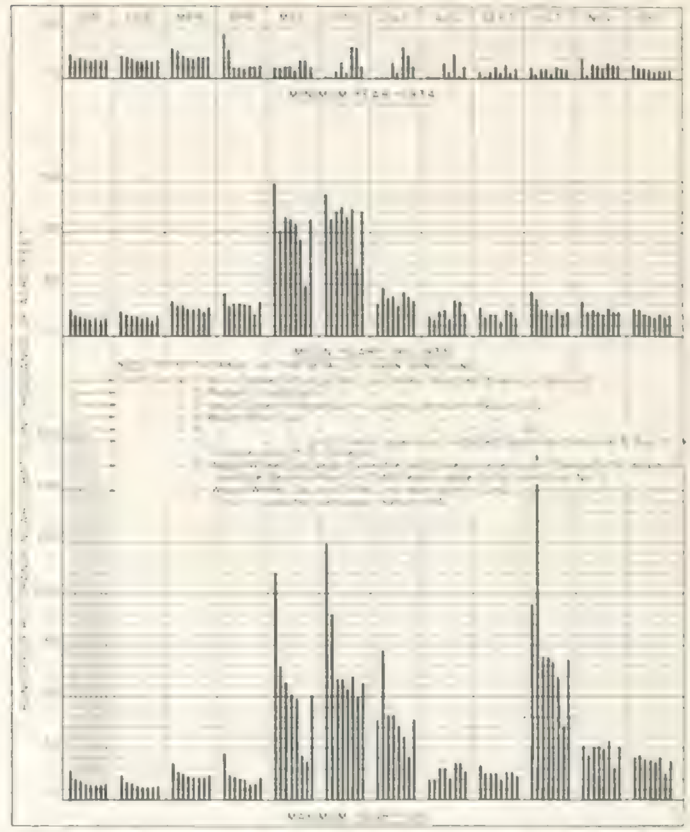
Condition No. 4.—Although under this Condition no shortages in the Rio Grande area of San Luis Valley are indicated in the 1911–35 period, some that are very severe are shown in the early period. There would have been shortages in 6 of the 13 years of this period with a maximum of 425,000 acre-feet, or 65 percent of the diversion demand, in 1902. Following 1904, however, there would have been a period of 33 years (including 1936 and 1937) without a shortage.

In the Middle Valley, shortages would have occurred in 1896, 1900, 1902, 1904, and 1934, with the maximum of 162,000 acre-feet, or 28 percent of the demand, in 1904. These shortages are substantially less than those shown under Condition No. 2, indicating the improvement of Middle Valley conditions that would be brought about by storage in the San Luis section as under Condition No. 4. A shortage free period of 30 years, 1905 to 1933, inclusive, is indicated here.

In the Elephant Butte-Fort Quitman section the maximum shortage in 1904 of 454,000 acre-feet, or 59 percent of the diversion demand, is 71,000 acre-feet more than the shortage in the same year under Condition No. 2. This increase is due to the greater use in the Middle Valley made possible by the more favorable monthly distribution of flow at Lobatos.



[illegible]



[illegible]—Monthly run-off of Rio Grande near Lobatos, Colo., for [illegible], mean, and maximum years, 1911 to 1935, under various given conditions of storage and irrigation draft.

Condition No. 5.—Shortages under this Condition are no different in San Luis Valley than under Condition No. 4. In the Middle Valley shortages are somewhat higher and occur in 3 more years than under Condition No. 4, but except for the shortage of 192,000 acre-feet in 1904, they are still all less than those under Condition No. 2. The shortage of 225,000 acre-feet or 39 percent, in 1934 is the maximum for any year in both periods.

In the Elephant Butte-Fort Quitman section the shortages occur in the same 3 years as under Condition No. 4 but are more severe. The maximum in 1904 of 480,000 acre-feet is 62 percent of the diversion demand. No shortages are indicated in the 1911–35 period, but the operation study showed a minimum content of Elephant Butte Reservoir of 364,000 acre-feet in 1935 as compared to 665,000 under Condition No. 4 (estimated by comparison with data of Condition No. 2) and 700,000 acre-feet under Condition No. 2.

Condition No. 6.—Shortages in the Conejos area under this Condition, in the 1911–35 period, are indicated for 2 years only, 1931 and 1934. The maximum of 36,000 acre-feet is 16 percent of the diversion demand. If the Mogote storage were eliminated, reducing the storage capacity to 132,000 acre-feet it is estimated that the maximum shortage in 1934 would have been about 33,000 acre-feet. Comparison of the data for years of low run-off in table 111 indicates decided improvement in the flow of Conejos River at its mouth due to storage regulation.

Condition No. 7.—Under this Condition, as shown in table 113, improvement in regulation of outflow at Lobatos is greater than under Condition No. 4. There is a shortage in the Middle Valley in the 1911–35 period in one year only, 1934, of 80,000 acre-feet. This is 81,000 acre-feet less than the shortage in the same year under Condition No. 4.

Condition No. 8.—With both Wagon Wheel Gap and Vega-Sylvestre Reservoirs, and greatest possible development in the Rio Grande area of San Luis Valley, this Condition shows a shortage in this area of 141,000 acre-feet, or 19 percent, in 1934, as compared to no shortages in the same period under Condition No. 4. Analysis for the early period was not made, but comparison with shortages in this period under Condition No. 4 indicates probable shortages under Condition No. 8 of from 35 to 70 percent of the diversion demand in 1899, 1900, 1901, 1902, and 1904.

Condition No. 9.—For maximum development in the Conejos area this Condition shows shortages in 6 years in the 1911–35 period as compared to only 2 years under Condition No. 6. The maximum of 151,000 acre-feet, or 50 percent, in 1934 is 115,000 acre-feet greater than the shortage in the same year under Condition No. 6.

Condition No. 10.—This is the Condition of unrestricted and maximum development in San Luis Valley. It shows a shortage in the Middle Valley in the 1911–35 period in 1 year only, 1934, amounting to 119,000 acre-feet, or 20 percent. This is more than the shortage under the comparable Condition No. 7 but less than that under Conditions Nos. 4 and 5, due to a somewhat better distribution of Lobatos flow in the summer and fall months.

No shortages are indicated in the 1911–35 period in the Elephant Butte-Fort Quitman section, but the operation study showed that the content of Elephant Butte Reservoir would have been reduced to 88,000 acre-feet in 1935.

Condition No. 11.—With respect to its effect in San Luis Valley, this Condition is no different than Conditions Nos. 4 and 5. In the Middle Valley, it shows that with the addition of storage in State Line Reservoir and inflow from the sump drain, no shortages occur in any year of the two periods of analysis.

In the Elephant Butte-Fort Quitman section, shortages in the early period in 1902, 1903, and 1904 are greater than under any of the Conditions Nos. 2, 4, and 5 because, with the elimination under Condition No. 11 of the shortages occurring in the Middle Valley under Conditions Nos. 2, 4, and 5, the greater consumption thus permitted in the Middle Valley is directly reflected in a reduction of flow to Elephant Butte Reservoir. The maximum shortage is 538,000 acre-feet, or 70 percent of the diversion demand, in 1904. In this period the operation studies showed that Elephant Butte Reservoir would have been dry from April to October, inclusive, 1902, in September and October 1903, and from April to August, inclusive, 1904. No shortages are indicated in the 1911–35 period. Elephant Butte Reservoir would have been drawn to a content of 205,000 acre-feet in September 1935.

In the operation study under this Condition, draft from State Line Reservoir to satisfy the Middle Valley demand was given priority over draft from El Vado Reservoir because there would be less loss by evaporation from water held in El Vado Reservoir than from water in State Line Reservoir. Under this procedure it turned out that no draft whatever was required on El Vado Reservoir in any year of the two periods. It remained full, therefore, in all years. Had the operation study been made (1) to draw to fullest extent on El Vado Reservoir to meet the Middle Valley demand (2) to complete satisfaction of this demand, if necessary, by drawing on State Line Reservoir, and finally (3) to draw on the latter reservoir to satisfy the Elephant Butte-Fort Quitman section demand to the fullest extent possible, the resulting shortage in the Elephant Butte-Fort Quitman section in 1902 would have been less by approximately the amount of residual storage in

TABLE 116.—*Water shortages in Elephant Butte-Fort Quitman section, Upper Rio Grande Basin, under various conditions of storage and irrigation draft*

[illegible]

[illegible]	Condition number[1]				
	[illegible]	[illegible]	[illegible]	[illegible]	11
[illegible]	0	0	0		0
[illegible]	0	[illegible]	[illegible]		0
[illegible]	0	[illegible]	[illegible]		[illegible]
[illegible]	0	0	[illegible]		[illegible]
[illegible]	0	0	[illegible]		0
[illegible]	0	[illegible]	[illegible]		[illegible]
[illegible]	0	0	0		[illegible]
[illegible]	0	0	0		[illegible]
[illegible]	0	0	0		[illegible]
[illegible]	0	0	0		0
1902	181.1	133.3	284.1		[illegible]
1903	5.0	6.2	7.0		17.8
1904	382.6	454.4	[illegible]		537.6
Maximum year in percent[2]	50	[illegible]	[illegible]		[illegible]
Minimum storage in Elephant Butte Reservoir	[illegible]	[3] 0	[illegible]		[illegible]
1911	0		0	0	0
1912	0		0	[illegible]	0
1913	0		0	0	[illegible]
1914	0		0	0	[illegible]
1915	0		0	0	[illegible]
1916	0		0	0	[illegible]
1917	0		0	0	[illegible]
1918	0		0	[illegible]	0
1919	0		0	0	0
1920	0		0	[illegible]	[illegible]
1921	0		0	0	[illegible]
1922	0		[illegible]	0	0
1923	0		0	0	[illegible]
1924	0		0	[illegible]	[illegible]
1925	0		0	[illegible]	[illegible]
1926	0		0	[illegible]	0
1927	0		0	0	[illegible]
1928	0		0	0	0
1929	0		0	0	[illegible]
1930	0		[illegible]	0	0
1931	0		0	0	0
1932	0		0	0	0
1933	0		0	0	0
1934	0		0	0	0
1935	0		0	0	0
Maximum year in percent[2]	0		0	[illegible]	0
Minimum storage in Elephant Butte Reservoir	700	[illegible]	[illegible]	88	205

[1] Refer to table 108.
[2] Maximum shortage in percent of diversion demand.
[3] Reservoir emptied in 3 consecutive years.
[4] Estimated.

El Vado and State Line Reservoirs as found at the end of that year. This was 198,000 and 167,000 acre-feet, respectively, or a total of 365,000 acre-feet, which would have reduced the 1902 shortage from 508,000 to 143,000 acre-feet, although Elephant Butte Reservoir would still have been emptied in that year. No relief would have been afforded for the 1903 and 1904 shortages.

Use of Transmountain Diversions

No analyses were made to show the effect of water brought to the San Luis section by the Animas-Rio Grande, Weminuche Pass, or San Juan-South Fork Rio Grande transmountain diversions prior to increase in storage capacity in Rio Grande drainage above the valley over that of the present. The largest mean annual importation of the three diversions would be 130,000 acre-feet under the Animas-Rio Grande project. The improvement in the regulation of water supply to be effected by this 130,000 acre-feet costing over 10

million dollars is not to be compared to that resulting from Wagon Wheel Gap Reservoir, providing 1,000,000 acre-feet storage at commensurate total cost. With Wagon Wheel Gap Reservoir constructed, the net effect of transmountain diversions which might be made in order to expand development in the valley would be to improve conditions in the lower sections over those under Condition No. 4 by the amount of any spills which might occur in the operation of terminal reservoirs, particularly if there were no increase in storage capacity over that which would be available in the present and Wagon Wheel Gap Reservoirs. In dry years the transmountain diversion supply would be reduced so that if encroachments were not made to further deplete the Lobatos flow, there would doubtless be heavy shortages in the new area brought under irrigation by the imported water.

As indicated by the shortages under the various Conditions, the San Juan-Chama transmountain diversion would be beneficial principally in relieving the shortages of Middle and Elephant Butte-Fort Quitman sections in a critical period such as that of 1899–1904 and in a year such as 1934, although, by the same token that there were shortages in these years, the San Juan supply, and hence the diversion, would probably be correspondingly short. However, for the Elephant Butte-Fort Quitman section, Elephant Butte Reservoir would provide the necessary regulation to overcome these diversion shortages, and for the Middle section, terminal storage could be provided to insure delivery to Rio Grande of the mean diversion yield every year. There would be opportunity for use of the imported water in development of new lands during the period of a generation or more when no shortages are indicated under any of the given conditions, but the new lands would of necessity suffer severe shortages in the minimum years when the transmountain diversion would be used to alleviate the shortages of the present developed areas.

PART I

APPENDIX A PRECIPITATION, EVAPORATION, AND STREAM FLOW RECORDS

Table 117.—*Precipitation in Upper Rio Grande Basin*

[Records of annual precipitation in inches as published by United States Weather Bureau]

SAN LUIS SECTION

	Garfield [1]	Salida [1]	Marshall Pass [1]	Cochetopa [1]	Westcliffe [1]	Hermit Lake [1]	Cathedral [1]	Saguache	Lake City [1]	Ironton [1]	Savage Basin [1]	Eureka	Ames [1]	Silverton [1]	Wagon Wheel Gap River Valley	Wagon Wheel Gap Exp. Station	Hermit (near)
1887								10.69									
1888								4.41									
1889								7.05									
1890					8.61												
1891																	
1892																	
1893																	
1894								5.79									
1895								14.01									
1896					13.27			2.88									
1897					21.36			8.84									
1898		11.34			16.88			8.06							12.26		
1899		9.02			12.81			5.96							12.25		14.53
1900		9.20	12.46		16.31			6.25							7.83		10.49
1901		9.76	13.48		17.59			6.86							9.73		
1902		7.01	18.57		15.24			7.09							10.28		
1903		10.14	15.11		18.85			6.51									
1904		14.36	16.33		15.95			7.26									
1905		12.84			14.98			3.76									
1906		17.74			16.09			12.50	17.61						25.05		
1907		12.92			11.75			11.19	15.06			25.86		27.23	16.56		
1908		10.19			11.71				12.70			28.85		25.50			
1909		15.46			15.42				16.83			32.22		29.30			
1910	17.61	12.30	9.72	9.87	10.11	29.52		7.78	14.36	25.30		22.57		24.24			16.00
1911	26.34	16.45	18.70	15.52	11.71	49.89		11.46	17.05	33.38		28.63		44.78		23.64	25.18
1912	20.65	12.71	23.64	10.06	10.81	43.26		8.31	13.96	28.35		20.20		27.44		15.32	16.27
1913	23.16	15.39	16.04	12.26	14.52	37.81		11.43	15.40	23.68		16.80		26.85		17.99	20.99
1914	26.21	13.49	15.56	14.70	18.16			14.97	17.17	25.41		20.19	29.17	27.11		24.26	19.70
1915	23.78	16.26	14.91	7.53	14.50			11.81		20.21	42.47		24.80	22.05		19.62	18.96
1916	25.21	14.94	19.99	12.40	11.20			7.71		28.79	52.62		35.10	34.84	22.24	20.09	23.66
1917	18.83	6.94			12.13			9.92		18.38	35.61		15.59	16.65	10.32	14.72	15.46
1918	26.31	11.69			16.17		9.73	13.43		21.28	48.78		23.79	21.95	12.37	18.15	21.12
1919	22.59	12.46			22.26		11.73	10.12		21.68	32.56		27.89	26.84	17.04	18.21	22.55
1920	23.86	10.20			13.17			11.63			37.83		27.24	20.73		17.54	23.10
1921	22.52						13.82				29.03		27.73	31.66		15.84	15.41
1922	21.44	10.52					12.75				33.02		23.32	18.42		19.95	15.59
1923	28.80						15.31	15.64			33.99		26.08	26.15		18.65	21.39
1924	17.25							6.48			38.67		22.41	19.87		12.42	11.75
1925	18.17										40.64		23.61	36.34		19.44	14.86
1926	19.97										27.95		28.43	28.71			13.21
1927	27.62										46.50		32.43	34.56			22.46
1928	20.34						11.04	7.66			37.96		20.20	22.80			16.71
1929	27.47						14.06	7.31			37.88		24.39	26.88			16.36
1930	19.25						14.67	8.19			35.30		24.11	18.42			17.21
1931	18.31						11.17	10.52					15.90	22.72			18.35
1932	21.57	10.54					12.24	9.34					21.13	28.39			11.55
1933	21.51	11.05			34.25		11.82	7.47					18.20	21.69			16.57
1934		7.92			14.22			5.15					13.50	18.12			10.75
1935		10.65			28.08			11.70					20.39	22.30			17.88
Mean	22.45	11.91	16.20	11.76	15.80	40.12	12.58	8.87	15.57	24.64	38.18	24.41	23.88	25.95	14.17	18.39	17.43
Estimated mean, 1890–1935	20.0	11.6	16.1	10.5	16.3	....	12.1	8.9	14.6	21.9	36.7	22.6	24.0	25.0	14.8	15.5	16.9

	Garnett	Del Norte	Cascade [1]	La Veta Pass	Monte Vista	Pagosa Springs (near) [1]	Palisade Lake [1]	Blanca	Cuchara Camps [1]	Platora	La Jara	Pagosa Springs [1]	North Lake [1]	San Luis	Manassa	Stonewall [1]	Cumbres
1887																	
1888																	
1889					5.01												
1890					6.59								16.54				
1891	9.20				9.17					37.67			23.89	18.85			54.79
1892	4.63				8.54								21.82	11.04			25.95
1893	4.46				6.22						7.15		23.90	10.97			
1894	6.33				6.23						6.75		22.28	10.58			
1895	10.37				9.62						9.44		32.55	15.76			
1896	3.61												24.00	12.31			
1897	6.25												31.76	13.93			
1898	4.60												27.31	14.20			
1899	6.96												18.49	10.04			
1900	3.54												23.08	10.16			
1901	4.50												21.31	13.02			
1902	8.18												15.21	7.45			
1903	5.18												19.17	6.98			
1904	9.51												22.79	9.56			
1905	7.08												23.00	10.14			
1906	9.05												19.47	10.85	8.40	20.94	
1907	7.62		42.60									23.02		7.91	7.45	18.62	

[1] Not actually in Rio Grande drainage but adjacent.

TABLE 117.—*Precipitation in Upper Rio Grande Basin*—Continued

SAN LUIS SECTION—Continued

	Garnett	[illegible]	Cas-[illegible]	[illegible]	Monte Vista	Pagosa Springs (near)[1]	Pali-sade [illegible]	Blanca	Cuchara [illegible]	[illegible]	[illegible]	Pagosa Springs[1]	North [illegible]	San [illegible]	[illegible]	Stone-[illegible][1]	Cum-bres
[illegible]	[illegible]		[illegible]									21.67	[illegible]	11.07	5.93	14.50	
[illegible]	9.41		[illegible]	23.31				9.87	23.65			25.86	[illegible]	[illegible]	6.36	18.62	
1910	[illegible]		[illegible]	15.51				[illegible]	15.02	22.03		16.14	[illegible]	9.64	4.91	[illegible]	[illegible]
[illegible]	9.08		[illegible]	[illegible]				13.27	23.74	40.33		32.10	20.74	17.64	[illegible]	20.69	46.90
1912	4.80		33.10	17.18					28.51	22.57		19.15	18.49	9.73	5.05	18.97	[illegible]
[illegible]	8.43		30.37	17.46				9.24	27.14	27.46		19.72	21.49	[illegible]	6.78	19.13	[illegible]
[illegible]	8.90		40.30	21.56				9.87	25.79	31.23		[illegible]	28.92	11.03	11.57	25.20	32.45
[illegible]	7.91		32.59	22.91				10.95	27.12	28.91		[illegible]	[illegible]	12.00	8.35	19.52	29.21
1916	[illegible]		44.70	[illegible]				7.07	22.94	39.07		34.84	30.09	[illegible]	7.28		36.66
1917	[illegible]		25.33	[illegible]					18.82	26.22			15.57	6.76	[illegible]		21.52
[illegible]	8.44		29.73	22.65			35.18		32.98				27.56	11.48	8.19		33.32
1919	[illegible]		31.52	[illegible]			[illegible]		[illegible]				30.72	9.23	7.43		35.67
1920	[illegible]	[illegible]	23.08	17.85			37.23		28.31	30.17				[illegible]	7.59		27.99
[illegible]	8.09	7.67	26.34	28.77			39.26		22.22						6.04		29.63
1922	[illegible]		[illegible]	14.59			34.11		25.60					8.56	4.95		29.84
1923	[illegible]		[illegible]	26.17			32.96		40.21					[illegible]	8.71		27.59
[illegible]	[illegible]	[illegible]	[illegible]	14.73			23.45		[illegible]				[illegible]		6.83		28.73
[illegible]	[illegible]	7.53	28.90	16.79			35.50	6.69	21.41				18.74		6.14		28.31
[illegible]	6.18		27.23	34.32			30.05	10.12	28.61				22.42		5.10		27.61
[illegible]	8.85	[illegible]	33.56	33.87			48.45		18.44				[illegible]		[illegible]		26.51
1928	[illegible]	7.59	16.07	33.40				[illegible]	[illegible]				[illegible]		6.30		[illegible]
[illegible]	8.48	[illegible]	26.60	22.83				[illegible]	25.37				22.68		6.32		35.37
[illegible]	6.97	6.29	19.53	25.60					22.14				26.65		5.40		36.46
1931	[illegible]	[illegible]	27.05	25.06		34.22			20.58				[illegible]		7.36		[illegible]
1932	5.42	[illegible]	23.72	20.71					[illegible]				19.47		5.17		39.22
[illegible]	6.31	11.13	17.13	16.21					21.46				17.21		6.72		34.88
1934	4.59	4.76	11.39	[illegible]					18.15				13.22		5.14		21.74
[illegible]	7.21	10.13	21.76	12.02		36.32			23.19				[illegible]		9.68		[illegible]
[illegible]	6.76	8.14	29.26	21.41	7.34	35.27	35.70	9.07	23.91	30.57	7.78	23.96	22.02	11.15	[illegible]	18.71	[illegible]
Estimated mean 1890–1935	6.7	8.1	27.4	21.3	7.7		37.7	8.7	23.9	26.7		22.5	22.2	[illegible]	[illegible]	[illegible]	31.1

MIDDLE SECTION

	Cos-tilla	[illegible]	[illegible]nero[1]	Chama	San [illegible] Station	Sun-[illegible] (near)	Cerro	[illegible] Mtn	Tierra [illegible]rilla	[illegible] River Canyon	Eagle [illegible] Station	[illegible] Grove Ranch	[illegible]	[illegible]beth-town[1]	[illegible]	Servil-[illegible]	[illegible]	Therma (near)[1]	Taos Can-[illegible]
1889			14.15	14.83									14.60						
[illegible]			18.05	[illegible]									[illegible]						
1891			25.11	32.82															
[illegible]			13.39	19.58															
1893			20.63	24.70															
[illegible]			13.62	20.18															
1895			18.01	27.55															
[illegible]			12.54	18.65									13.91						
[illegible]			[illegible]	33.07									27.13						
[illegible]			[illegible]										14.51						
1899			15.34																
[illegible]																			
1901																			
[illegible]																			
[illegible]																			
[illegible]																			
[illegible]				16.85									16.09	[illegible]					
1906		19.34		25.17						[illegible]			16.58	16.71					
[illegible]		17.89		25.30						24.31			15.16	13.26					
[illegible]		14.88		20.21						20.72			15.23	17.21					
[illegible]		[illegible]		21.31						20.65		15.31	[illegible]	20.87	15.17				21.32
[illegible]		12.98		17.30		11.39				[illegible]		21.78	12.05	14.20	15.52				[illegible]
[illegible]		[illegible]		[illegible]		18.16		31.01		21.16		28.81	[illegible]	27.09	29.26				26.31
1912		12.66		18.95		[illegible]		[illegible]		22.32		18.43	9.12	15.06	20.06				16.81
1913		19.09		[illegible]		[illegible]		32.18		25.38		17.85	16.58	18.10	23.69				[illegible]
[illegible]	[illegible]	[illegible]		26.01		11.79		[illegible]		28.13	16.59	25.21	[illegible]	20.78	[illegible]				23.61
[illegible]	12.59	18.48		[illegible]		14.40		37.21		18.88	17.28	19.66	[illegible]	[illegible]	[illegible]				[illegible]
[illegible]	[illegible]	18.70		[illegible]		11.10		31.11		21.44	14.12	36.48	17.63	21.06	33.04		[illegible]		22.27
[illegible]	7.59	12.83		[illegible]	[illegible]			[illegible]		17.97	[illegible]	17.16	12.69	[illegible]	[illegible]		11.71		12.21
1918		[illegible]		21.23	14.91	[illegible]		33.97		23.78	17.00	23.55	18.10	20.14	[illegible]				22.64
[illegible]	14.86	21.99		[illegible]	20.30	17.07		[illegible]		27.61	17.72	31.21	20.62	21.85	[illegible]				26.08
1920	13.29	[illegible]		22.27	[illegible]	15.08		25.22		[illegible]	16.39	17.35	16.96	14.21	27.52	13.52	17.05		20.73
[illegible]	18.51	18.41		[illegible]	11.41	[illegible]				25.82	18.42	[illegible]	[illegible]	17.21	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]		12.85		18.76	12.76	[illegible]				[illegible]	14.37	20.15	[illegible]	14.43	17.32	[illegible]	12.95		[illegible]
[illegible]		23.57		23.76	17.91	[illegible]				[illegible]	18.80	[illegible]	[illegible]	23.81	31.83	14.71	27.70		18.78
[illegible]		18.03		17.65	[illegible]	13.05				21.50	[illegible]	21.52	[illegible]	[illegible]	[illegible]	[illegible]	10.63		18.68
[illegible]		[illegible]		21.91	[illegible]	10.45				20.99	[illegible]	[illegible]	12.01	15.14	[illegible]	[illegible]	11.84		[illegible]
[illegible]		19.15		[illegible]	17.24	12.74				21.12	12.57	26.78	[illegible]	13.33	22.67	[illegible]	[illegible]		15.25
1927		[illegible]		29.19	18.45	12.80				[illegible]	18.28	[illegible]	[illegible]	[illegible]	29.92	17.35			20.57
[illegible]		[illegible]		11.32	15.33	11.44				18.95	12.61	[illegible]	[illegible]	15.09	17.15	[illegible]			[illegible]
[illegible]		15.67		25.25		12.68				25.73	17.25	26.88	17.77	20.63	[illegible]				24.27
1930		14.19		17.66		[illegible]				23.09	[illegible]	21.93	15.28	18.99	[illegible]				[illegible]
[illegible]		28.61		27.24						24.23		23.55	17.84	18.18	[illegible]				21.24
1932		18.03		[illegible]			[illegible]			22.98		23.59	11.63	[illegible]	[illegible]			[illegible]	17.11
[illegible]		14.90		17.22			[illegible]		[illegible]	[illegible]		[illegible]	[illegible]	12.60	[illegible]			[illegible]	16.39
1934		[illegible]		[illegible]			18.13		12.57	18.33		13.88	11.05	13.26	[illegible]			13.75	[illegible]
[illegible]		[illegible]		22.37			15.40		22.92	[illegible]		25.79	[illegible]	18.07	[illegible]			20.81	21.28
[illegible]	13.33	18.42	[illegible]	22.29	[illegible]	[illegible]	14.03	[illegible]	17.31	22.17	15.71	23.09	15.94	17.20	23.37	[illegible]	17.23	15.65	[illegible]
[illegible]	12.7	18.5	16.1	22.3	15.0	11.1		21.2		22.5	[illegible]	23.5	[illegible]	17.3	[illegible]	13.4	18.4		20.3

[1] [illegible]

TABLE 117.—*Precipitation in Upper Rio Grande Basin*—Continued

MIDDLE SECTION—Continued

	Gavilan (near)	Taos	El Rito	[illegible][1]	Aurora[1]	Black Lake[1]	[illegible]	[illegible][1]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1889		11.10							11.19										
1890		13.73							11.59										
1891		14.31							13.47										
1892		9.53							8.15										
1893		10.26							8.34									19.06	
1894		11.81																19.94	
1895		18.60													12.60			21.42	
1896		13.36													8.08			13.66	
1897															10.92				
1898															7.78				
1899															6.25				
1900															10.20				
1901		16.74													11.00				
1902		10.75													7.37				
1903		11.72																	
1904		11.77																	
1905		12.09													11.19				
1906		13.52													10.90				
1907		13.74													15.55				
1908		15.31													10.21				
1909		15.45			19.54	15.49					17.34			10.99	9.99	[illegible]			
1910		8.94			12.71	10.02					13.22			13.35	6.02	7.24			12.02
1911		18.78			25.17	18.46					26.51			21.97	15.38	15.55			23.99
1912		9.77			18.89	14.27					22.43			14.10	9.05	9.07	12.99		15.52
1913		11.72			27.04	16.62					22.36			15.85	7.66	[illegible]	23.77		22.39
1914		11.70			20.66	15.84		15.15		18.30	21.54			20.65	11.10	10.87	21.73		17.88
1915		13.46			23.37	16.38		11.75		15.84	17.19			16.32	11.44	10.38	23.11		[illegible]
1916		14.07			20.05	16.75	16.69	8.96		[illegible]	25.30			17.21	13.44	6.20	26.91		30.22
1917		8.71			13.93	12.16	12.18	6.78		11.04	[illegible]			7.39	5.85	4.97	13.13		9.36
1918		15.91			22.36	20.03	[illegible]	9.08		20.99	25.53			17.67	11.05	9.42	[illegible]		[illegible]
1919		17.37			27.22	21.13	20.29			25.63	29.47			20.34	16.02	11.69	31.23		29.17
1920		13.28			21.30	16.15	14.30	[illegible]		16.91	20.51			18.35	13.23	7.07	22.10		17.81
1921		16.10		16.12	25.07	[illegible]	23.11	17.43			25.46			16.74	10.86	11.80	23.72		
1922		9.06		4.94	16.51	10.91	10.24	8.39		[illegible]	14.22			11.46	6.68	4.89	13.67		9.96
1923	17.67	14.28		13.00	24.62	18.98	15.77	16.12		[illegible]	23.12		19.89	17.24	11.69	9.72	23.15		21.12
1924	13.70	10.60		14.17	15.68	11.49	10.50	11.60		14.22	16.85		12.65	11.49	5.35		19.25		15.17
1925	13.94	11.56		9.09	19.62	17.14	10.59	15.46		15.83	20.38		14.46	16.05	5.59		19.11		17.46
1926		11.72		7.38	19.72	16.00	11.72	13.13		16.01	23.22		17.25	15.08	9.92		21.25		19.40
1927	20.07	12.98		26.69	20.48	19.86	17.11			18.86	19.65		16.01	15.23	5.41		26.22		17.32
1928		9.86		16.66	19.79	13.27	9.13			11.93	16.18		12.72	13.50	7.97		16.59		14.45
1929	18.69	15.55		24.67	20.34	19.20	20.07			[illegible]	23.41		20.92	24.07	16.00		27.03		20.50
1930	14.96	12.09		15.07	22.23	17.52	14.25			12.54	[illegible]		16.35	12.22			18.80		16.92
1931	25.77	13.47	12.56		18.27	21.58				21.25	22.03	21.51		17.50			27.42		21.92
1932	13.76	11.07	10.68		19.42	16.36				12.64	19.60	16.38		14.73			24.26		16.63
1933	17.49	10.78	9.84		19.90	15.21				15.29	14.33	16.24		12.05			21.88		18.75
1934	17.16	10.94	12.36		15.70	13.42				14.90	13.15	17.09		11.17			19.93		13.54
1935	22.25	13.39			18.73	17.42				19.25	24.33	18.84		14.95			30.18		19.36
Mean	17.77	12.88	11.36	14.78	20.53	16.38	14.95	11.80	10.55	16.46	[illegible]	18.01	16.28	15.47	10.05	9.19	22.00	15.58	18.55
Estimated mean 1890-1935	18.1	13.0		15.6	20.6	16.8	15.0	12.2	11.7	16.8	21.0	18.3	16.8	16.1	9.8	9.2	22.2		19.0

MIDDLE SECTION—Continued

	Nambe	Frijoles Canyon	Lee Ranch	Jemez Springs	Winsor's Ranch[1]	Bland	Santa Fe	Santa Fe Canyon	Crownpoint	Woodbury	Fort Wingate	Galisteo	McGaffey Ranger Station[1]	Bernalillo	Bluewater	Diener	Stanley	San Rafael	Albuquerque
1850							9.10												4.92
1851							13.23												5.31
1852							21.72												13.81
1853							21.77												7.10
1854							24.80												12.51
1855							24.18												[illegible]
1856							23.07												4.15
1857							8.52												5.20
1858							11.35												16.30
1859							9.49												5.95
1860							8.83												3.78
1861							15.81												[illegible]
1862							11.32												
1863							7.75												12.66
1864							21.80				11.64								[illegible]
1865							23.15				10.38								[illegible]
1866							11.52				10.82								[illegible]
1867							7.79				23.30								6.68
1868							8.92				14.37								
1869							12.08				19.14								
1870							13.93				16.59								
1871							12.15				22.25								
1872							9.87				21.47								
1873							10.23				26.00								
1874							19.93				7.55								
1875							18.97				10.73								
1876							15.07				[illegible]								
1877							13.15				10.09								
1878							19.55				[illegible]								

[1] Not actually in Rio Grande drainage but adjacent.

TABLE 117.—*Precipitation in Upper Rio Grande Basin*—Continued

MIDDLE SECTION—Continued

	[illegible]	[illegible]	Las [illegible]	[illegible]	[illegible] Ranch [1]	[illegible]	[illegible]	Santa Fe Canyon	Crown-[illegible] [1]	Woodbury	Fort [illegible] [1]	[illegible]	[illegible] Ranger Station [1]	Bernal-[illegible]	Bluewater	Diener	Stan-[illegible] (near) [1]	San [illegible]	Albuquerque
1879							[illegible]				[illegible]								8.61
[illegible]							9.89				11.06								
[illegible]							22.25				13.93								
[illegible]							11.37				14.32								
[illegible]							14.76				14.44								
[illegible]							[illegible]				16.45								
1885							14.81				14.05								
[illegible]							15.90				12.44								
1887							13.38				[illegible]								
[illegible]							12.03				11.40								
[illegible]	[illegible]						7.89				12.22			5.89					5.40
[illegible]	[illegible]						12.88				17.87			10.29					8.72
[illegible]	16.60						[illegible]				14.27			8.90					[illegible]
[illegible]	8.10						11.62				8.72			[illegible]					6.84
[illegible]							14.94				9.62								7.42
[illegible]							13.31				14.48	16.71							5.72
[illegible]					[illegible]		[illegible]				17.14	14.29		10.64					9.78
[illegible]					22.08		[illegible]				10.63	[illegible]		7.89	10.17				7.02
[illegible]					25.49		[illegible]				18.94	17.55		11.49	12.40				9.74
1898					23.19		[illegible]				13.89	9.30		5.82	8.07				[illegible]
[illegible]					19.05		10.05				8.40	11.59		6.89	9.90				7.34
[illegible]					23.70		15.89			[illegible]	9.40	11.96		[illegible]	9.08				5.90
[illegible]					[illegible]		17.41		....	15.39	9.72	16.09		10.88	9.05				10.19
1902					[illegible]		13.36			[illegible]	12.37	7.91			7.05				[illegible]
[illegible]					19.54		9.79				10.34	8.50							5.83
[illegible]					21.34		14.19				15.96							8.41	6.82
[illegible]					26.32		17.22				21.21							19.26	15.73
[illegible]					25.62		16.60				22.96							[illegible]	8.36
1907					27.97		15.15				[illegible]							18.57	9.18
[illegible]					26.36		12.79				[illegible]				[illegible]			12.23	7.61
[illegible]					24.05		12.26				[illegible]				[illegible]		8.66	21.40	4.42
[illegible]				13.44	19.93		8.65	9.46			9.84				[illegible]		6.31	8.87	7.41
[illegible]				23.25	31.75		17.12	21.24			18.71		18.71		17.23		23.31	18.01	11.94
[illegible]				[illegible]	18.15		10.29	15.83					16.01		5.14		11.02	9.20	6.09
[illegible]				17.25	26.42		15.01	[illegible]					24.39		7.98		12.59	11.15	6.67
1914				21.76	28.50	[illegible]	17.26	[illegible]	12.85						10.05		13.39	15.94	11.39
1915				21.22	22.85	[illegible]	17.86	[illegible]	8.57						8.76		17.14	16.73	9.66
[illegible]				22.96	23.43	21.09	16.41	[illegible]	11.59				16.55		9.84		16.28		11.54
1917				9.25	17.22	11.34	5.03		5.03				11.15		6.34		7.60		3.29
[illegible]				18.48	24.27	18.32	15.25		[illegible]				14.75		9.08		12.02		7.63
[illegible]				24.29	37.25	30.55	20.83		16.99				19.75		10.65		17.75		15.03
[illegible]				16.28	22.86	21.47	13.24		8.25				11.41				11.38		6.26
[illegible]				16.82	31.60	17.49	17.80		11.66				24.02			21.86	12.72		10.29
[illegible]				11.77	17.60	12.89	10.29		7.68				14.31			38.22	6.41		4.09
1923				18.85	24.87	18.56	14.23	[illegible]	15.86				18.73	8.82		26.65	15.65		7.95
[illegible]		12.31	19.60	14.60	21.49		8.92	11.68	14.53				10.46	6.47		21.83	5.29		6.37
1925		[illegible]	20.69	[illegible]	26.62	[illegible]	12.64	[illegible]	11.18				14.03		[illegible]	20.52	8.34		5.48
1926		[illegible]	[illegible]	18.10	28.50	[illegible]	12.97	19.86	9.71				22.06		10.45	22.82	12.65		9.21
1927		[illegible]	23.09	[illegible]	23.48	[illegible]	14.17	16.43	17.26				23.28		18.40	23.31			7.67
[illegible]		12.68	14.02	15.70	24.61		13.08	23.01	11.41				14.20		8.95				8.41
[illegible]		19.19	24.51	[illegible]	32.14		21.52		13.49				20.88		11.04		[illegible]		[illegible]
[illegible]	[illegible]	14.18	19.22	14.87	25.14		13.24		7.28				15.74		7.43		8.35		8.31
[illegible]	[illegible]	[illegible]	31.85	28.12	31.14		15.90		[illegible]				23.93		18.47				10.79
[illegible]		14.26	21.83	16.02	[illegible]		[illegible]		12.86				[illegible]		12.43		17.13		9.78
[illegible]		[illegible]	[illegible]	19.96	22.74		13.11		10.21				19.36		14.79		12.94		11.39
[illegible]			17.68	17.76	18.07		13.26		7.63				16.66		9.65		5.95		6.98
[illegible]		14.83	27.83	22.80	23.90		12.89		11.60				20.43		14.46		11.84		11.04
[illegible]	11.62	15.80	22.69	[illegible]	24.49	19.07	14.43	17.70	11.25	11.66	14.45	12.61	17.80	8.16	10.54	[illegible]	[illegible]	[illegible]	8.21
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[2] 14.3	[illegible]	11.2	[illegible]	15.1	[illegible]	18.3	[illegible]	10.7	25.3	[illegible]	[illegible]	8.5

[illegible]
[illegible]

TABLE 117.—*Precipitation in Upper Rio Grande Basin*—Continued

MIDDLE SECTION—Continued

	San Fidel	Upper Canyon Ranger Station	Barton [1]	Laguna	Rio Grande Industrial School	Moriarty (near)[1]	[illegible] Ranch	Tajique (near)[1]	Estancia (near)[1]	Los Lunas (near)	Mountainair [1]	Bernardo [1]	Datil [1]	Magdalena	Monte Prieto [1]	Socorro	Rosedale (near)	San Marcial
1850				9.69														[illegible]
1851				[illegible]														[illegible]
1852																		[illegible]
1853																		5.76
1854																		[illegible]
1855																		12.56
1856																		[illegible]
1857																		[illegible]
1858																		4.63
1859																		[illegible]
1860																		[illegible]
1861																		10.65
1862																		19.68
1863																		
1864																		
1865																		[illegible]
1866																		7.47
1867																		[illegible]
1868																		17.44
1869																		[illegible]
1870																		9.14
1871																		7.28
1872																		6.18
1873																		5.85
1874																		9.08
1875																		13.31
1876																		[illegible]
1877																		12.45
1878																		6.08
1879																8.94		8.94
1880																14.36		[illegible]
1881																15.33		15.33
1882																		
1883																		
1884																		10.00
1885																		
1886																		
1887																		
1888																		
1889									15.10	8.31				8.78			9.50	[illegible]
1890									12.18	7.38				13.43			12.28	7.17
1891									11.12	16.37						13.96	12.78	[illegible]
1892									8.03	6.11						4.31	9.57	4.31
1893										8.40						8.06	11.19	8.06
1894										4.55						5.07	10.88	[illegible]
1895										12.30						13.55	15.98	12.08
1896										7.65						10.58	18.93	6.55
1897										7.36						10.61	18.18	[illegible]
1898										11.57						9.12		10.08
1899										7.05						7.71		6.78
1900										8.05						7.05		4.39
1901										14.77						10.06		1.08
1902										5.71	14.26					6.38		6.83
1903										6.38	13.01							7.57
1904									10.82	10.45	10.90					10.34		4.16
1905				21.27					16.41	13.65	22.82		24.17	21.96		22.40	[illegible]	21.79
1906				13.05					14.76	11.67	17.06		11.95	12.22		11.60	16.57	[illegible]
1907				12.07					14.91	15.85	22.86		14.11	15.98		17.85	20.90	16.06
1908				8.35					14.01	[illegible]	16.57		14.00	14.76		6.29	16.34	[illegible]
1909				10.60		8.85			9.88	4.25	16.50			12.85		8.11	12.56	6.22
1910		11.35		9.08		8.52	12.55		[illegible]	4.51	12.56			10.28		7.62	13.56	6.83
1911		17.46		12.90	[illegible]	19.57	23.87		19.13	11.57	20.49			19.88		16.12	27.59	15.66
1912		11.66		8.47	5.03	14.48	20.49		11.09	5.47	14.72			13.98		8.01	21.53	9.48
1913		16.56		8.68	7.28	13.54	23.22		10.29	[illegible]	14.27			13.96		8.10	15.16	[illegible]
1914		18.70	[illegible]	15.44	10.04	15.07	29.73		15.13	10.21	19.48			23.84		17.81	21.40	8.38
1915		17.94	20.98	13.13	9.67	18.72	39.32		15.23	12.13	16.48			15.81		16.57	21.84	[illegible]
1916		17.80	21.72		10.28	14.49	39.42		17.35	10.14			16.15	17.10		16.38	17.89	9.93
1917		8.93	6.53		3.23	8.04	16.67		7.73	2.15	10.80		8.67	6.67		4.69	10.15	3.25
1918		17.52	15.34		8.88	8.84	29.32		17.09	9.94	22.19		11.67	11.55		12.22	17.13	[illegible]
1919		24.05	26.56	14.48	13.50	15.24	27.84		16.33	10.84	16.77		16.19	16.17		16.31	21.04	9.32
1920	11.20	12.09	17.30	13.81	6.16			19.39	13.93	6.27	15.41		16.43	13.39		8.61	15.00	[illegible]
1921	10.35	13.97	16.53	10.85	8.49			20.47	16.42	9.26	15.18		13.68	7.73		12.53	10.50	[illegible]
1922	3.15	7.81	8.04		3.66			12.10		3.24			7.33	4.25		4.86	5.37	[illegible]
1923	15.89	16.14	14.53					22.07	12.65	9.07	19.42		14.41	16.20		8.80	14.56	[illegible]
1924	4.93	10.50	12.72	5.81				19.67	6.89	5.83			7.48	7.68		5.04	10.20	5.72
1925	8.55	[illegible]	10.88					[illegible]	9.94	8.37			[illegible]	7.99		4.12	9.34	5.79
1926	10.78	15.91						23.67	13.63	8.11	17.23		10.72	9.49		11.24	15.35	[illegible]
1927	13.06	[illegible]		[illegible]				16.39	13.29	9.40			13.17	8.61		6.68	13.05	9.09
1928	11.10	12.34		8.65				18.56	11.05	10.26	12.91		11.24	[illegible]		6.98	11.29	6.07
1929	12.25	18.25		12.94				28.17	17.77	14.07	17.59		16.39	16.76		12.23	14.37	11.29
1930	7.95	11.01		7.14				15.70	10.77	5.08	16.41		9.20	7.87		6.52	10.98	7.98
1931	14.68			13.26				22.22	18.91	10.44	16.99		18.54	18.20		15.90	16.71	[illegible]
1932	12.83			10.89				23.19	17.72	10.15	19.09		15.35			10.30	12.70	10.03
1933	11.98	16.27		14.64				20.80	11.56	7.30	15.15		14.66		10.96	12.42		7.89
1934	7.23	12.59		7.43				10.88	8.37	4.34	6.82	5.47	14.01		7.21	6.79		5.50
1935	13.93	21.41						25.54	12.49	6.07	17.19	5.77	13.51	[illegible]	14.89	12.14		8.36
Mean	10.62	14.73	15.90	11.46	8.31	13.21	26.24	19.49	13.18	8.62	16.25	5.62	13.48	13.12	11.02	10.27	15.00	9.09
Estimated mean, [illegible]–1935	11.0	14.6	15.9	10.7	8.2	12.7	25.3	20.3	12.8	[2] 8.6	15.4		13.0	12.4		10.2	[illegible]	[2] 8.4

[1] Not actually in Rio Grande drainage but adjacent.
[2] Actual 46-year record.

Table 117.—Precipitation in Upper Rio Grande Basin—Continued

ELEPHANT BUTTE—FORT QUITMAN SECTION

Year	[illegible] Ranch	Chloride Ranger Station	[illegible]	Elephant Butte [illegible]	Graham's Ranch	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Jornada Exper'l Range	Agricultural College	[illegible]	Chamberino	Newman [1]	Lanark	El Paso	Clint	Fort [illegible]	Fort Quitman
1851												[illegible]								
1852												[illegible]								
1853												[illegible]								
1854								14.60				[illegible]								
1855								13.44				[illegible]								
1856								13.51				9.22					21.81			
1857								20.55				10.40								
1858								10.58				5.11					5.00			
1859												5.52					4.83			8.31
1860												3.61								[illegible]
1861												10.48								
1862																				
1863																				
1864				[illegible]																
1865				7.30								7.30								
1866												7.79								
1867												9.89					2.84			
1868				8.55								9.71								
1869				[illegible]								12.60								
1870				[illegible]								[illegible]								
1871				7.30								6.92					7.61			
1872				[illegible]								6.33					7.68			
1873				[illegible]								[illegible]					[illegible]			
1874				13.35								6.13					7.24			
1875				[illegible]								5.69					6.48			
1876												8.85					9.46			
1877												[illegible]								
1878												8.07								
1879												7.30					6.80			
1880				... ...								7.10					15.37			
1881												15.05					18.17			
1882												9.23					8.27			
1883																	12.92			
1884																	18.29			
1885																	7.31			
1886												[illegible]					8.06			
1887												7.42					6.76			
1888												[illegible]					[illegible]			
1889						13.15						7.07					7.10		7.17	
1890						13.96						6.93					8.49		4.89	
1891						8.35											[illegible]		3.33	
1892						7.85						6.51					5.32		6.96	
1893				...		15.89						10.82					10.88		14.86	
1894								[illegible]				4.47					4.24		7.18	
1895				9.11		12.23		11.87				9.47					10.20		12.40	
1896				10.84		12.21		[illegible]				7.99					9.79			
1897				[illegible]		17.13		11.74				8.96					12.41			
1898				14.38		10.54		11.13				11.21					6.16			
1899				7.72		4.60		5.45				9.67	4.97			6.50	7.30			
1900				[illegible]		6.43		6.03				8.40	6.94			7.44	7.95			
1901				8.49		9.19						11.96	7.71			16.36	8.68			
1902				6.19								10.90	6.64			5.08	10.15			
1903				6.76								10.29	8.02			14.06	11.63			
1904				12.18		13.20						10.13	11.46			8.98	11.30			
1905		[illegible]		16.96		23.77		[illegible]	25.09			17.09	9.62			16.13	17.80			
1906		14.98		8.72		19.19		13.27	[illegible]			8.80	[illegible]			5.59	14.99			
1907		[illegible]		9.78		13.27		9.86	12.42			[illegible]	10.51			5.83	8.41			
1908		[illegible]		8.13		[illegible]		8.86	10.73			5.97	[illegible]			5.90	6.94			
1909				[illegible]		7.13		5.43	7.93			4.94	9.00		5.37	4.82	4.33			
1910	11.34			5.79		5.40		4.81	6.31			4.02	3.38		4.73	5.10	4.02			
1911	[illegible]			13.51		15.89		11.21	[illegible]			[illegible]	[illegible]		[illegible]	10.73	10.88			
1912	[illegible]			10.95				14.91	11.67			9.20	13.15		16.43	[illegible]	10.14			
1913	[illegible]		[illegible]	[illegible]				[illegible]	17.06			11.73	8.58		[illegible]	[illegible]	7.09			
1914	[illegible]		[illegible]	[illegible]				11.50	22.36		11.78	11.85	13.11		19.65	7.19	17.02			
1915	[illegible]		[illegible]	13.87			16.30	[illegible]	11.63		7.66	7.37	8.74		9.82	[illegible]	10.26			
1916	[illegible]		21.06	13.73			[illegible]	13.27	14.73		8.88	7.78	[illegible]		10.15	[illegible]	7.77			
1917	[illegible]		9.32	3.53			11.88	[illegible]	5.01		[illegible]	5.58	5.74		4.88	[illegible]	6.49			
1918	[illegible]		17.88	[illegible]			[illegible]	10.16	15.31		8.76	7.23	11.28		[illegible]	10.52	8.21			
1919	[illegible]		[illegible]	[illegible]			[illegible]		10.95		12.78	[illegible]	9.01		12.04	12.82	9.87	11.46		
1920	[illegible]		[illegible]	[illegible]			15.99	10.53	[illegible]		[illegible]	[illegible]	8.00		7.86	9.85	6.21	6.64		
1921	[illegible]	[illegible]	[illegible]	[illegible]			13.47	9.23	11.29		5.72	7.64	6.18		8.25	[illegible]	[illegible]	5.95		
1922	[illegible]	[illegible]	[illegible]	3.77			11.76	6.89	7.09		6.69	[illegible]	[illegible]		5.30	3.01	[illegible]	3.68		
1923	[illegible]	18.83	[illegible]	[illegible]			[illegible]	[illegible]	17.49		9.18	10.36	12.17	7.21	6.88	8.34	8.13	8.59		
1924	[illegible]	8.62	11.16	4.77		[illegible]	13.14	15.19	6.23		[illegible]	4.83	5.58	6.27	5.06		7.28	[illegible]		
1925	[illegible]	[illegible]	[illegible]	5.99		[illegible]	20.91	[illegible]			[illegible]	7.80	8.32	7.28	8.28		[illegible]	[illegible]		
1926	[illegible]	[illegible]	21.29	[illegible]		16.43	18.91				17.73	[illegible]	16.02	12.68	11.20		11.73	13.34		
1927	[illegible]	[illegible]	[illegible]	6.87		[illegible]	11.12	[illegible]	11.28		7.69	9.47	9.50	5.54	4.72		6.25	[illegible]		
1928	[illegible]	[illegible]		10.98		[illegible]	19.26		11.62		9.78		7.16	4.28	10.16		8.21	9.39		
1929		[illegible]		[illegible]		[illegible]	19.04		16.64		11.04	9.22	9.72	8.15	[illegible]		9.29	8.47		
1930		[illegible]		8.82		6.72	15.86		11.44		5.73	6.88		[illegible]	8.37		6.09	5.83		
1931		[illegible]		11.42	11.74	[illegible]	24.52		17.35	[illegible]	12.24	[illegible]	12.31	11.42	11.18		10.79	14.41		
1932		16.68		[illegible]	9.73	13.60	22.37		15.49	7.43	[illegible]	[illegible]	12.89		8.51		[illegible]	10.80		
1933		[illegible]		8.08	12.93	12.12	18.36		15.08	[illegible]	[illegible]	4.71					[illegible]	6.10		
1934		[illegible]		[illegible]	[illegible]	...	17.38		12.58	4.03	[illegible]	4.62					2.73	3.31		
1935				[illegible]	10.67	11.12	[illegible]		14.82	[illegible]	[illegible]	12.67					5.65	...		
[illegible]	11.86	[illegible]	17.70	9.99	10.35	[illegible]	18.14	10.37	13.56	8.87	9.18	[illegible]	[illegible]	7.63	9.05	8.20	[illegible]	[illegible]	8.11	6.26
[illegible]	12.1	[illegible]	17.8	9.7	10.9	12.1	[illegible]	[illegible]	[illegible]	9.1	[illegible]	8.6	8.6	7.3	9.2	8.0	[illegible]	8.8	[illegible]	

TABLE 118.—*Evaporation at Wagon Wheel Gap, Colo.*

[Standard Weather Bureau class A evaporation pan. Unit, inches]

Year	January	February	March	April	May	June	July	August	September	October	November	December
STATION A-1, ELEVATION 9,601, NORTHERN EXPOSURE												
1919								3.11	1.66			
1920						3.73	3.52	2.60	[1] 1.54	[illegible]		
1921						3.81	3.19	1.83	1.98	[3] .53		
1922					[4] 0.96	4.20	4.16	2.41	2.00	[2] .48		
1923					[5] .45	5.16	3.49	2.15	[6] 1.51			
1924						5.20	3.75	3.07	2.27			
STATION A-2, ELEVATION 9,609, SOUTHERN EXPOSURE												
1919								5.31	4.13	[1] 2.71		
1920						4.59	4.87	[illegible]	3.98	[7] 1.90		
1921						5.13	4.80	3.88	5.12	[8] 2.91		
1922					[4] 1.31	5.41	5.84	4.56	4.58	[illegible]		
1923					[5] .52	[illegible]	[illegible]	4.57	3.58	[illegible]		
1924						7.30	6.16	6.00	5.14	[11] 1.58		

[1] 27 days.
[2] 1st to 10th, inclusive.
[3] 1st to 20th, inclusive.
[4] 25th to 31st.
[5] 28th to 31st.
[6] 1st to 28th.
[7] 1st to 19th.
[8] 1st to 27th.
[9] 29 days.
[10] 1st to 25th, inclusive.
[11] 1st to 11th, inclusive.

Records from U. S. Forest Service. Stations maintained in connection with the Wagon Wheel Gap Experiment Station on the Rio Grande above San Luis Valley.

TABLE 119.—*Evaporation at Garnett, San Luis Valley, Colo.*

[Standard Weather Bureau class A evaporation pan. Unit, inches]

Year	January	February	March	April	May	June	July	August	September	October	November	December
1927						8.84	8.02	6.18	5.00	[illegible]		
1928				5.76	7.68	10.68	9.24	7.80	6.00	[1] 4.44		
1930				[2] 1.72	9.22	9.43	7.93	[illegible]	[illegible]	4.36		
1931				[3] 4.69	8.47	10.45	9.42	7.87	[illegible]	[illegible]	[4] 1.27	

[1] 1st to 26th, inclusive.
[2] 8 days.
[3] 15th to 30th, inclusive.
[4] 1st to 15th.

Records from Colorado State Engineer.

TABLE 120.—*Evaporation near Therma, N. Mex.* [1]

[Standard Weather Bureau class A evaporation pan. Unit, inches]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1930		1.60	1.47		7.31	8.59	6.22	4.65	5.57	4.33	[2] [illegible]	0.60	
1931				5.70	7.78	9.88	7.92	6.43	5.40	[illegible]			
1932	0.80	1.12	3.11	5.58	7.93	11.14	12.31	10.25	9.27	5.85	1.90	.80	70.36
1933													
1934				5.93	7.02	12.20		7.00		5.85			
1935				[illegible]	6.80	9.41	8.28	6.80	5.30	4.83			

[1] Station on west shore Eagle's Nest Reservoir in Taos County.
[2] Partially estimated.

Records previous to 1934 from New Mexico State Engineer.
Records from April 1934 to October 1935 from U. S. Weather Bureau.

TABLE 121.—*Evaporation at Santa Fe, N. Mex.*

[Standard Weather Bureau class A evaporation pan. Unit, inches]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1913					8.36	6.65	7.23	[illegible]	5.54	5.15	3.29	2.66	
1914	1.96	2.20	3.85	5.65	5.95	10.19	6.24	5.97	6.28	4.41	4.43		
1915													
1916													
1917	3.14	2.88	5.58	7.22	7.64	11.89	9.95	9.04	6.79	[illegible]	3.36	2.39	75.82
1918	1.08	2.30	3.81	6.13	9.78	10.24	9.29	8.17	6.68	4.30	1.96	1.47	65.21
1919	[illegible]	1.02	2.70	5.50	8.29	9.38	6.81	7.47	[illegible]	[illegible]	2.80	1.57	56.40
1920	1.59	2.10	3.91	5.56	8.52	9.04	8.61	7.50	6.53	[illegible]	2.01	1.71	61.72
1921	1.38	2.32	[illegible]	6.44	8.88	8.68	8.13	6.64	6.91	4.93	3.26	1.18	[illegible]
1922	1.12	2.16	3.60	5.77	10.18	[illegible]	10.26	8.92	7.12	5.18	1.86	1.26	68.18
1923	1.81	.96	3.44	6.28	8.58	10.60	8.75	6.71	4.77	3.82	1.97	1.06	58.75
1924	.92	2.24	[illegible]	[illegible]	8.35	11.99	8.81	9.28	7.76	6.15	3.30	1.20	68.60
1925	1.54	2.28	5.08	8.22	9.01	10.29	[illegible]	7.47	[illegible]	4.47	2.03	.77	67.41
1926	.83	3.01	[illegible]	4.76	5.92	8.78	9.18	[illegible]	6.71	[illegible]	2.93	1.02	61.35
1927	1.72	2.10	4.03	6.70	12.24	9.31	9.31	[illegible]	5.46	5.29	2.87	1.08	68.20
1928	1.45	1.93	4.31	6.02	6.84	11.21	10.01	7.55	7.51	4.58	1.59	1.66	64.66
1929	1.26	1.95	3.73	7.05	9.67	11.85	8.41	6.86	6.62	4.51	1.89	1.41	65.21
1930	1.40	2.71	3.60	7.28	8.59	10.74	8.19	7.22	6.86	4.28	1.93	1.20	64.00
1931	1.23	2.46	3.73	5.50	8.63	10.73	8.99	7.43	5.53	4.51	2.17	1.82	62.73
1932	1.83	2.56	[illegible]	7.06	8.81	10.00	9.15	5.59	4.69	2.44	[illegible]	[1] 1.13	58.78
1933	[1] 1.35	[1] [illegible]	[illegible]	[1] 6.47	7.66	8.36	8.89	7.65	6.39	3.91	[1] 2.08	[1] 1.13	60.61
17-year mean	1.50	2.19	[illegible]	6.33	8.68	10.21	8.96	7.71	6.38	[illegible]	2.36	1.38	64.19
Percent of mean annual	2.34	3.41	6.12	9.86	13.52	15.91	13.96	12.01	9.94	[illegible]	[illegible]	2.15	100.00

[1] Estimate as published in Water Bulletin No. 3 of International Boundary Commission.

Records previous to January 1917 from reports of New Mexico State Engineer.
Records from January 1917 to October 1933 from U. S. Weather Bureau except as noted.

TABLE 122.—*Evaporation at Los Griegos station, near Albuquerque, N. Mex.*

[illegible]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
[illegible]									7.02	5.00	[illegible]	1.27	...
[illegible]	1.45	3.22	6.22	8.36	13.24	10.20	11.24	9.12	[illegible]	[illegible]	3.38	1.45	80.12
[illegible]	2.02	2.90	6.17	8.62	8.10	12.73	11.01	8.38	7.33			.78	
[illegible]													
[illegible]	[illegible]	4.28	5.29	7.87	[illegible]	9.53	[illegible]	9.33	8.00	5.53	2.91	1.44	[illegible]
[illegible]	1.52	1.73	5.90	[illegible]	10.14	11.78	11.34	[illegible]	[illegible]	5.70	4.61	2.09	77.40
[illegible]	1.63	2.48	5.40										

[illegible]
Records from December 1927 to December 1928 from U. S. Weather Bureau.
[illegible]

TABLE 123.—*Evaporation at Elephant Butte Dam, N. Mex.*

[illegible]

[illegible]	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1916					[illegible]	[illegible]	11.83	9.55	9.11	7.21	4.90	[illegible]	[illegible]
[illegible]	2.14	4.13	[illegible]	12.93	[illegible]	[illegible]	13.25	11.81	9.00	[illegible]	5.12	3.96	109.68
[illegible]	3.18	[illegible]	8.21	11.32	15.71	[illegible]	[illegible]	11.60	10.17	6.72	3.69	[1] 1.71	105.74
[illegible]	[1] [illegible]	[1] 4.85	7.20	9.19	12.66	[illegible]	11.14	11.13	7.88	7.82	3.98	[illegible]	92.66
[illegible]	1.92	3.91	8.37	10.47	14.16	12.47	13.50	10.66	9.96	8.61	3.66	[illegible]	101.16
[illegible]	3.56	4.88	8.16	10.98	14.26	13.07	10.24	9.87	9.74	9.41	[illegible]	3.68	103.19
[illegible]	3.67	[illegible]	8.06	11.19	14.34	11.09	13.85	12.19	8.97	[illegible]	3.80	2.75	[illegible]
[illegible]	3.85	3.31	6.76	11.19	14.49	17.06	12.33	9.10	7.83	7.44	2.76	3.83	99.86
[illegible]	2.55	3.85	[illegible]	8.76	11.57	14.97	10.74	11.40	10.57	[illegible]	5.04	2.78	[illegible]
1925	2.44	[illegible]	8.24	11.08	11.74	15.38	11.96	10.80	9.29	6.81	4.15	2.51	99.06
[illegible]	1.73	[illegible]	5.30	6.99	[illegible]	[illegible]	12.02	11.01	7.27	5.93	4.15	[illegible]	84.25
[illegible]	3.09	4.76	7.85	10.22	11.83	13.42	12.38	[illegible]	7.61	6.61	4.71	[illegible]	96.91
[illegible]	2.80	2.80	7.71	9.10	9.81	14.48	12.10	9.62	8.32	5.87	2.75	2.18	87.54
[illegible]	3.45	4.19	7.31	11.13	12.01	14.20	9.93	7.98	7.45	4.54	2.51	2.31	87.01
[illegible]	2.52	4.37	6.23	9.75	11.71	12.01	9.58	9.10	[illegible]	6.37	3.05	1.78	84.56
[illegible]	1.72	2.25	6.75	6.71	10.34	11.56	10.42	[illegible]	[illegible]	5.90	[illegible]	1.98	75.98
[illegible]	2.24	4.68	6.20	9.61	11.20	[illegible]	9.72	8.99	7.87	4.72	3.64	2.23	82.96
[illegible]	2.34	3.18	7.22	[illegible]	11.77	9.93	13.10	11.17	[illegible]	[illegible]	4.51	[illegible]	91.89
[illegible]	3.29	5.23	8.57	11.27	14.78	17.48	16.69	14.08	11.30	[illegible]	4.94	2.70	[illegible]
[illegible]	3.22	4.17	9.20	12.30	12.58	16.80	15.97	10.85	8.05	[illegible]	4.86	2.40	[illegible]
[illegible]	2.69	4.28	7.61	10.13	12.70	13.90	12.23	10.46	8.73	[illegible]	[illegible]	2.70	[illegible]
[illegible]	2.79	[illegible]	7.88	10.49	[illegible]	14.40	12.67	10.83	9.04	7.38	4.14	[illegible]	[illegible]

[1] [illegible]
[2] [illegible]

Records from U. S. Weather Bureau except as noted.
NOTE.—Evaporation from 1926 to July 1933 is stated to have been influenced by the shade of trees growing near the evaporation pan. Station was relocated on July 7, 1933

TABLE 124.—*Evaporation at Jornada experimental range, New Mexico* [1]

[Floating evaporation pan 36 inches square and 18 inches deep. Unit, inches]

[illegible]	January	February	March	April	May	June	July	August	September	October	November	December	Annual
[illegible]					.....	14.70	11.25	[illegible]	7.83	5.88	2.07	2.93	
[illegible]	3.31	4.98	7.05	[illegible]	13.22	13.22	11.04	9.21	9.18	7.13	4.11	1.93	93.93
[illegible]	[illegible]	2.67	7.81	[illegible]	11.14	12.79	11.03	[illegible]	[illegible]	7.52	4.23	2.14	88.92
[illegible]		4.28	..								3.91	2.33	
[illegible]	2.48	3.67	[illegible]	[illegible]	12.36	11.35							
[illegible]	...											....	
[illegible]	3.16	[illegible]	[illegible]	[illegible]	[illegible]	13.41	13.94	9.70	7.18	7.00	3.86	1.89	94.58

[1] Meteorological station of U. S. Forest Service 18 miles northeast of Las Cruces.

Records previous to January 1932 from reports of New Mexico State Engineer
Records from January 1932 to December 1935 from U. S. Weather Bureau.

TABLE 125.—*Evaporation at agricultural college, near Las Cruces, N. Mex.*

[illegible]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
[illegible]									[illegible]	[illegible]	3.62	2.18	
[illegible]	[illegible]	[illegible]	7.75	[illegible]	[illegible]	13.50	12.89	11.48	7.47	5.53	[illegible]	2.66	94.18
[illegible]	[illegible]	4.05	7.16	10.40	11.99	11.62	12.90	9.88	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	4.58	[illegible]	[illegible]	11.64	12.35	[illegible]	[illegible]	[illegible]	[illegible]	4.38	[illegible]	93.12
[illegible]	[illegible]	5.84	[illegible]	[illegible]	[illegible]	[illegible]	13.24	11.02	[illegible]	5.72	3.45	2.72	98.03
[illegible]	3.37	[illegible]	[illegible]	[illegible]	[illegible]	11.28	11.30	[illegible]	[illegible]	[illegible]	3.00	1.85	84.74
[illegible]	[illegible]	4.39	7.09	[illegible]	[illegible]	[illegible]	9.06	[illegible]	[illegible]	7.08	4.18	2.44	86.16
[illegible]	2.73	5.34	[illegible]	9.39	[illegible]	[illegible]	9.14	[illegible]	6.80	4.99	3.50	2.39	[illegible]
[illegible]	1.91	4.65	5.15	7.29	[illegible]	10.56	[illegible]	9.30	7.24	4.59	3.63	2.09	[illegible]

[illegible]

TABLE 125.—*Evaporation at agricultural college, near Las Cruces, N. Mex.*—Continued

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1927	3.22	4.42	7.25	9.28	[illegible]	10.28	10.20	7.89	6.84	[illegible]	4.38	2.17	83.46
1928	3.03	4.15	8.16	[illegible]	9.52	11.78	10.82	7.80	6.92	[illegible]	2.67	2.78	81.93
1929	3.20	4.31	7.11	8.88	10.41	11.60	9.12	7.75	[illegible]	5.01	2.59	2.55	79.58
1930	2.75	4.74	6.43	8.54	10.86	[illegible]	9.90	9.05	7.76	5.93	3.74	2.17	83.76
1931	2.59	[illegible]	7.15	7.73	18.84	11.92	10.25	[illegible]	7.48	6.88	[illegible]	[illegible]	90.72
1932	2.99	[illegible]	7.63	11.20	13.36	14.22	13.40	12.26	9.42	5.66	4.18	2.50	100.82
1933	2.75	4.16	9.41	10.28	14.15	12.28	[illegible]	11.08	9.79	6.20	4.11	3.54	[illegible]
1934	3.22	4.99	7.76	11.12	12.93	14.54	14.94	13.10	10.48	7.21	4.68	2.82	107.79
1935	3.45	3.93	8.41	11.61	11.66	15.13	15.37	12.02	7.43	7.18	4.41	2.62	103.22
17-year mean	[illegible]	4.33	7.56	9.57	11.89	12.29	11.58	9.87	7.97	[illegible]	3.73	2.62	90.31
Percent of mean annual	3.27	4.79	8.37	10.59	13.16	13.60	12.82	10.93	8.82	6.62	4.13	2.90	100.00

Records from U. S. Weather Bureau.

TABLE 126.—*Run-off of Rio Grande at Thirty-Mile Bridge, Colo.*

[Drainage area 163 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1909						(1)	27.3	15.2	27.8				
1910						[illegible]	10.6	6.2	4.0	3.8	2.5		
1911				[illegible]	39.8	78.6	44.1	11.4	7.6	(1)			
1912				(1)	47.0	79.7	34.6	15.0	5.8	4.8	.5		
1913			0.2	3.9	31.5	26.1	32.7	16.9	7.7				
1914				.3	25.8	69.6	47.7	21.2	6.0	5.8	4.1		
1915	0.9	0.8	.9	.9	13.0	61.3	50.0	24.3	3.1	13.2	2.7	[illegible]	172.3
1916	3.2	2.8	5.4	7.9	29.8	24.2	40.8	24.8	5.6	36.1	16.7		
1917	1.0	.3	.3	.4	9.4	109.0	56.0	21.2	9.6	9.1	5.1	.4	[illegible]
1918	.5	.4	.5	5.7	31.7	[illegible]	14.3	11.1	3.0	4.0			
1919	[illegible]	.3	.3	2.9	38.4	[illegible]	31.5	30.8	7.7	5.7	[illegible]	.2	[illegible]
1920	[illegible]	.2	.2	[illegible]	30.5	79.1	51.8	19.8	7.3	6.8	1.6	.5	[illegible]
1921	[illegible]	.4	.5	7.9	22.4	102.0	46.9	25.3	7.8	11.8	3.0	[2].5	232.0
1922					39.0	60.7	46.4	24.4	7.7	6.0	[3].9	[2].6	
1923	[2].6	[2].6	[2].6	6.5	31.6	35.6	43.5	26.2	3.7				
1924													
1925					(1)	45.9	38.5	19.0	13.1				
1926					(1)	66.6	39.3	29.9	7.3	.3	1.3	[2].6	
1927	[2].6	[illegible]	[illegible]	5.6	21.6	67.2	[illegible]	24.2	16.5	21.8	[2]1.7	[2]1.7	212.6
1928	[2]1.7	[2]1.6	[2]1.7	18.0	30.3	54.9	36.1	14.6	6.3	3.8	2.6	[2]2.1	173.7
1929	[2]2.1	[2]1.9	[2]2.1	6.9	16.0	52.6	44.5	24.7	17.1	20.8	3.7	[2].5	192.9
1930	[illegible]	.4	[2].5	9.3	35.6	48.2	19.6	19.0	4.8	6.2	[2].2	[2].2	144.5
1931	[2].2	[2].2	[2].2	4.4	17.3	30.9	8.8	[illegible]	4.4	5.1	.9	[2].2	77.0
1932	[2].2	[2].2	[2].2	11.8	13.6	49.2	41.6	32.9	7.4	8.0	[2].2	[2].2	165.5
1933	[2].2	[2].2	[2].2	7.1	22.9	44.5	30.9	9.8	[illegible]	4.8	[illegible]	[2].2	127.1
1934	[2].2	[2].2	[3]1.1	18.6	31.9	8.3	3.3	4.0	[illegible]	2.8	1.3	[2].1	79.3
1935	[2].1	[2].1	1.4	8.5	13.8	26.4	36.1	29.0	5.5	3.1	[2].4	[2].4	124.8

[1] Partial record.
[2] Estimated.
[3] Partially estimated.

Records as published by U. S. Geological Survey; previous to October 1913 from Water Supply Paper No. 358.
Records from October 1913 to September 1934 from biennial reports of the Colorado State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 127.—*Run-off of Rio Grande at Wason, Colo.*

[Drainage area 700 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in percent of mean
1890 [1]	7.0	5.0	15.0	30.0	148.0	152.0	66.0	30.0	17.0	19.0	13.0	10.0	512.0	113.6
1891 [1]	9.0	7.0	14.0	47.0	116.0	165.0	74.0	32.0	22.0	34.0	14.0	11.0	545.0	120.9
1892 [1]	[illegible]	7.0	10.0	34.0	95.0	83.0	30.0	23.0	12.0	11.0	9.0	6.0	329.0	73.0
1893 [1]	4.0	4.0	7.0	17.0	74.0	65.0	15.0	18.0	13.0	11.0	9.0	6.0	243.0	53.9
1894 [1]	5.0	4.0	9.0	30.0	88.0	36.0	14.0	20.0	16.0	15.0	10.0	7.0	254.0	56.4
1895 [1]	6.0	5.0	14.0	67.0	85.0	89.0	44.0	35.0	19.0	17.0	13.0	10.0	404.0	89.7
1896 [1]	9.0	8.0	17.0	51.0	90.0	27.0	15.0	15.0	21.0	19.0	11.0	7.0	290.0	64.4
1897 [1]	7.0	5.0	15.0	35.0	124.0	133.0	48.0	24.0	26.0	59.0	25.0	14.0	515.0	114.2
1898 [1]	12.0	9.0	15.0	64.0	98.0	175.0	71.0	26.0	15.0	11.0	8.0	6.0	510.0	113.2
1899 [1]	5.0	4.0	19.0	19.0	56.0	36.0	29.0	30.0	16.0	19.0	15.0	7.0	255.0	56.6
1900 [1]	4.0	5.0	7.0	13.0	101.0	104.0	23.0	14.0	12.0	14.0	9.0	6.0	312.0	69.2
1901 [1]	[illegible]	4.0	6.0	23.0	94.0	72.0	24.0	24.0	19.0	11.0	10.0	6.0	299.0	66.4
1902 [1]	4.0	3.0	7.0	20.0	49.0	17.0	4.0	11.0	10.0	10.0	8.0	5.0	148.0	32.8
1903	[illegible]	[2]7.0	[3]1.0	[1]24.0	[1]102.0	[1]208.0	[1]72.0	[1]26.0	[1]22.0	[1]15.0	[illegible]	[3]6.0	497.0	110.3
1904	[illegible]	[2]3.0	[3]2.0	[illegible]	[1]48.0	[1]22.0	[1]11.0	[1]33.0	[1]29.0	[1]58.0	[3]9.0	[3]6.0	243.0	53.9
1905	[3]8.0	[3]4.0	[3]14.0	[illegible]	[1]120.0	[1]246.0	[illegible]	[1]29.0	[1]17.0	[1]18.0	[1]11.0	[1]7.0	546.0	121.2
1906	5.0	4.0	10.0	36.0	133.0	199.0	83.0	37.0	30.0	36.0	20.0	10.0	603.0	133.8
1907	[3]13.0	[3]11.0	[3]12.0	[2]46.0	102.0	226.0	213.0	62.7	37.4	20.7	14.0	[3]7.0	764.8	169.7
1908	[2]6.0	[2]5.0	11.0	28.7	73.2	137.0	55.6	48.9	18.6	13.9	9.7	[3]4.0	411.6	[illegible]
1909	[3]6.0	[3]5.0	[3]8.0	30.1	134.0	219.0	70.1	38.7	76.2	26.7	16.8	[1]14.0	644.6	143.0
1910	11.1	8.3	29.7	53.6	143.0	107.0	26.8	19.9	[illegible]	14.2	11.8	9.4	449.0	99.6
1911	9.2	8.1	9.5	29.0	110.0	182.0	114.0	47.6	28.2	79.9	24.6	14.3	656.4	145.7

See footnotes at end of table.

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	July	[illegible]	[illegible]	October	[illegible]ber	Decem-[illegible]	[illegible]	Annual run-off in percent of mean
1912	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	81.5	42.1	18.5	17.8	[illegible]	[1] 6.0	574.8	127.6
1913	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	59.3	34.7	19.8	[1] 23.0	[1] 14.0	[1] 11.0	349.7	77.6
[illegible]	[1] 9.0	[1] 8.0	[1] 8.0	[illegible]	[illegible]	182.0	96.0	[illegible]	37.2	40.0	14.1	6.3	575.5	127.7
[illegible]	5.7	5.7	7.0	[illegible]	[illegible]	143.0	91.6	53.7	32.7	26.6	11.5	[illegible]	461.7	102.5
[illegible]	[illegible]	9.3	[illegible]	28.1	[illegible]	110.0	[illegible]	69.5	23.1	74.4	35.5	[1] 10.0	[illegible]	126.9
[illegible]	[1] 9.0	[1] 8.0	[illegible]	17.0	62.7	237.0	122.0	[illegible]	25.9	18.9	11.2	5.7	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	8.4	[illegible]	[illegible]	[illegible]	[illegible]	41.1	23.4	13.9	9.0	[1] 6.0	328.8	73.0
[illegible]	5.8	6.1	6.7	[illegible]	[illegible]	105.0	83.0	62.7	23.7	15.0	8.5	7.3	483.1	107.2
[illegible]	[1] 8.0	[1] 8.0	7.1	[illegible]	[illegible]	221.0	112.0	52.5	21.5	15.9	13.1	9.8	[illegible]	140.4
[illegible]	8.8	7.9	[illegible]	29.1	[illegible]	[illegible]	121.0	72.6	33.3	[illegible]	15.3	9.2	730.8	[illegible]
[illegible]	[illegible]	[1] 8.0	[1] 9.0	[illegible]	[illegible]	[illegible]	80.6	60.0	25.3	14.8	8.3	6.8	558.8	124.0
[illegible]	[illegible]	[illegible]	9.2	[illegible]	[illegible]	[illegible]	82.4	[illegible]	31.4	23.7	18.3	15.9	506.0	112.3
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	81.8	50.3	14.6	[illegible]	[illegible]	6.0	501.8	111.4
[illegible]	[illegible]	[illegible]	[illegible]	31.8	[illegible]	[illegible]	71.9	39.7	30.7	[illegible]	[illegible]	14.4	428.4	95.1
[illegible]	[illegible]	[illegible]	[illegible]	18.5	77.5	126.0	75.6	55.2	21.2	[illegible]	[illegible]	7.7	428.1	95.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	73.2	49.6	[illegible]	9.5	588.7	130.6
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36.8	17.5	[illegible]	10.7	6.8	423.2	[illegible]
[illegible]	[illegible]	[illegible]	8.1	[illegible]	[illegible]	[illegible]	[illegible]	65.8	50.0	38.1	12.6	6.8	525.2	116.6
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41.6	16.8	18.6	8.4	5.0	378.1	83.9
[illegible]	[illegible]	[illegible]	5.8	16.8	[illegible]	[illegible]	[illegible]	15.6	16.3	19.2	8.8	5.8	[illegible]	54.9
[illegible]	[illegible]	5.2	6.8	31.4	[illegible]	126.0	87.3	81.8	25.0	17.2	5.7	4.9	500.4	111.0
[illegible]	[illegible]	4.2	[illegible]	16.9	[illegible]	99.4	56.8	28.7	18.1	11.9	7.9	6.8	321.2	[illegible]
[illegible]	5.5	4.2	8.0	45.0	71.9	22.1	12.7	13.5	13.6	9.3	6.1	4.7	216.6	48.1
[illegible]	4.2	4.3	[illegible]	21.4	41.5	124.0	76.2	57.4	18.6	12.6	6.0	5.0	378.3	84.0
[illegible]	[illegible]	6.0	10.1	29.1	95.8	128.1	66.3	40.1	24.4	23.8	12.0	7.9	[illegible]	
[illegible]	[illegible]	1.33	2.24	[illegible]	[illegible]	[illegible]	[illegible]	8.91	5.42	[illegible]	2.66	1.75	100.0	

[illegible]

TABLE 128.—*Run-off of Rio Grande near Del Norte, Colo.*

[Drainage area 1,320 square miles. Unit, 1,000 acre-feet]

[illegible]	[illegible]	[illegible]	March	[illegible]	May	June	July	[illegible]	Septem-[illegible]	October	November	December	Annual	Annual run-off in percent [illegible]
[illegible]	13.5	11.1	27.4	[illegible]	[illegible]	227.0	93.2	[illegible]	[illegible]	[illegible]	20.2	18.4	820.4	116.1
[illegible]	[illegible]	[illegible]	26.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22.3	19.1	859.9	121.6
1892	[illegible]	[illegible]	19.4	[illegible]	[illegible]	[illegible]	45.5	27.3	[illegible]	[illegible]	14.3	10.8	532.4	75.3
1893	[illegible]	[illegible]	[illegible]	31.7	120.0	[illegible]	24.3	19.9	16.1	16.2	11.3	10.8	392.2	55.5
[illegible]	[illegible]	9.7	18.4	54.9	147.0	[illegible]	22.1	23.6	21.1	22.1	16.8	13.8	[illegible]	60.0
[illegible]	[illegible]	[illegible]	26.7	119.0	141.0	[illegible]	64.6	45.2	26.7	25.8	20.4	18.4	649.7	91.9
1896	[illegible]	[illegible]	[illegible]	91.0	151.0	[illegible]	24.3	16.5	29.7	27.9	18.1	13.8	487.0	68.9
1897	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	68.1	[illegible]	[illegible]	[illegible]	39.6	24.0	823.4	116.5
1898	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	101.0	31.3	[illegible]	[illegible]	13.1	11.1	797.9	112.8
1899	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	43.2	36.7	[illegible]	[illegible]	23.8	12.6	393.4	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0	33.6	14.0	[illegible]	[illegible]	14.9	[illegible]	506.1	71.6
[illegible]	[illegible]	9.7	13.8	42.2	[illegible]	116.0	[illegible]	[illegible]	26.5	[illegible]	16.8	10.8	487.2	68.9
1902	[illegible]	8.3	[illegible]	38.0	71.9	36.8	9.4	11.1	12.3	14.9	12.9	9.8	249.3	35.3
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	102.0	32.3	30.6	[illegible]	[1] 17.0	[1] 11.0	760.4	107.5
[illegible]	[illegible]	[1] 7.0	[1] 12.0	[illegible]	71.2	42.6	20.7	42.4	41.2	89.1	[1] 21.0	[1] 13.0	405.5	57.4
[illegible]	[illegible]	[illegible]	[illegible]	45.2	210.0	362.0	67.1	35.5	22.4	26.4	17.6	12.3	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	18.8	61.9	[illegible]	[illegible]	116.0	47.7	[illegible]	54.8	32.5	18.4	949.0	134.3
[illegible]	[illegible]	[illegible]	[illegible]	[2] 95.0	[2] 161.0	[illegible]	[3] 279.0	[3] 92.8	[3] 48.4	[3] 30.4	[3] 20.8	[1] 14.0	1,164.4	164.7
[illegible]	[illegible]	[illegible]	[4] 21.0	[4] 45.0	[illegible]	171.0	[illegible]	57.2	[illegible]	16.7	12.2	[1] 12.0	540.4	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[4] 49.0	196.0	284.0	93.5	53.1	[illegible]	[illegible]	[illegible]	24.4	909.3	128.6
[illegible]	[illegible]	[illegible]	39.7	83.3	210.0	141.0	38.0	30.3	[illegible]	[illegible]	[illegible]	13.4	654.9	92.6
[illegible]	[illegible]	[illegible]	20.7	57.0	[illegible]	287.0	172.0	59.5	[illegible]	[illegible]	[illegible]	[illegible]	1,076.7	[illegible]
[illegible]	[illegible]	15.7	17.1	34.4	229.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	811.7	114.7
1913	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22.8	18.6	564.6	[illegible]
1914	[illegible]	[illegible]	[2] 15.0	18.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16.5	10.6	791.3	111.9
[illegible]	[illegible]	12.4	15.9	37.2	106.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17.4	12.5	[illegible]	94.6
[illegible]	[illegible]	[illegible]	34.1	56.5	[illegible]	196.0	[illegible]	[illegible]	[illegible]	100.0	47.8	[2] 20.0	930.1	131.5
[illegible]	[illegible]	[2] 16.0	[2] 18.0	37.9	114.0	359.0	184.0	65.2	33.8	25.2	17.6	10.8	899.5	127.2
1918	11.7	10.8	16.4	28.7	116.0	143.0	64.0	48.6	34.2	22.4	15.6	[illegible]	523.4	74.0
1919	[illegible]	11.7	18.0	[illegible]	223.0	162.0	116.0	77.5	31.7	[illegible]	18.3	15.1	772.7	109.3
[illegible]	14.6	15.6	[illegible]	30.2	[illegible]	355.0	[illegible]	68.2	[illegible]	[illegible]	21.4	15.6	1,001.0	141.7
1921	15.5	13.7	21.9	43.0	[illegible]	371.0	156.0	99.0	50.9	42.6	23.3	15.6	1,038.5	147.0
1922	17.9	15.2	18.1	39.8	[illegible]	305.0	119.0	81.8	33.4	20.0	15.0	13.9	951.1	134.6
1923	12.8	10.6	16.0	38.6	188.0	214.0	[illegible]	84.0	53.9	[illegible]	33.6	22.2	838.3	118.6
[illegible]	17.8	[illegible]	17.2	68.4	227.0	202.0	103.0	58.2	[illegible]	19.1	11.4	12.4	770.0	[illegible]
[illegible]	11.9	11.9	22.3	[illegible]	141.0	160.0	97.2	[illegible]	45.8	42.7	24.1	[illegible]	[illegible]	99.4
[illegible]	17.8	13.3	14.8	34.3	138.0	[illegible]	103.0	71.9	[illegible]	20.2	[illegible]	14.1	[illegible]	94.6
[illegible]	11.7	11.7	13.5	54.0	179.0	[illegible]	161.0	80.6	119.0	75.0	25.1	18.8	966.4	136.8
[illegible]	18.1	17.3	[illegible]	49.0	[illegible]	165.0	108.0	48.8	25.0	[illegible]	17.9	15.1	676.7	95.8
[illegible]	[illegible]	12.2	[illegible]	[illegible]	186.0	229.0	157.0	104.0	82.7	57.7	23.4	14.1	897.5	[illegible]
[illegible]	12.3	[illegible]	15.4	56.6	108.0	140.0	75.6	58.6	[illegible]	24.5	12.7	12.1	[illegible]	78.0

[illegible]

TABLE 128.—*Runoff of Rio Grande near Del Norte, Colo.*—Continued

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual [illegible]
1931	8.3	9.3	12.3	28.2	73.8	99.4	35.4	18.7	23.1	30.4	12.2	10.2	[illegible]	[illegible]
1932	11.4	11.3	16.5	66.6	214.0	236.0	146.0	106.0	30.6	26.3	10.9	9.5	[illegible]	125.2
1933	10.2	8.6	14.4	23.6	81.2	169.0	79.3	39.4	27.1	24.2	14.7	12.9	[illegible]	71.4
1934	13.2	11.1	15.1	67.2	103.0	28.3	14.7	15.9	17.9	14.4	11.3	8.3	320.4	45.3
1935	8.5	9.1	15.3	37.1	81.9	263.0	128.0	72.2	27.9	19.5	12.7	8.3	683.5	96.7
Mean	13.5	12.2	19.5	52.4	163.2	197.5	92.3	51.9	34.3	36.2	19.6	11.5	707.1	
Percent of annual	1.91	1.73	2.76	7.41	23.08	27.93	13.05	7.34	4.85	5.12	2.77	[illegible]	100.0	

All records previous to October 1913 as published in U. S. Geological Survey Water Supply Paper No. 358 except as noted.
Records from October 1913 to September 1934 from biennial reports of the Colorado State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 129.—*Run-off of Rio Grande near Monte Vista, Colo.*

[Drainage area, 1,590 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1926					48.8	77.4	18.4	1.6	1.6	2.6	14.7		
1927				18.2	48.3	107.0	89.8	13.6	98.2	57.3	18.3		
1928				15.5	58.3	48.1	12.4	2.9	3.2	2.3	9.9		
1929				19.5	56.0	74.4	29.1	60.1	64.3	35.0	22.4		
1930				15.6	29.6	36.4	14.1	13.0	1.5	3.9	11.6		
1931			(1)	1.9	19.5	27.4	7.7	2.9	4.2	3.8	[illegible]		
1932			[2] 11.7	16.8	66.4	100.0	39.4	14.6	3.4	4.4	12.0		
1933			(1)	2.8	22.0	44.0	13.9	4.4	4.4	3.2	10.1		
1934		[2] 7.8	3.4	18.4	33.8	7.2	4.4	3.6	3.2	.8	2.4	10.9	
1935	11.4	5.9	[illegible]	4.6	27.0	104.0	31.6	8.5	4.7	4.6	9.7	9.2	221.7

[1] Partial record.
[2] Partially estimated.

Records from May 1926 to September 1934 from biennial reports of the Colorado State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 130.—*Run-off of Rio Grande at Alamosa, Colo.*

[Drainage area, 1,712 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1890 [1]	8.0	12.0	15.0	30.0	83.0	88.0	33.0	15.0	8.0	12.0	15.0	17.0	336.0
1891 [1]	17.0	14.0	22.0	35.0	119.0	119.0	54.0	20.0	7.0	59.0	23.0	14.0	503.0
1892 [1]	11.0	14.0	26.0	44.0	80.0	58.0	7.0	1.0	.2	1.0	2.0	5.0	249.2
1893 [1]	1.0	5.0	10.0	20.0	32.0	42.0	1.0	1.0	1.0	1.0	1.0	5.0	120.0
1894 [1]	1.0	2.0	15.0	17.0	18.0	5.0	1.0	1.0	.2	16.0	1.0	6.0	83.2
1895 [1]	10.0	9.0	18.0	36.0	24.0	55.0	27.0	26.0	12.0	9.0	15.0	13.0	254.0
1896 [1]	14.0	12.0	24.0	25.0	11.0	7.0	2.0	1.0	.2	2.0	4.0	8.0	110.2
1897 [1]	5.0	5.0	11.0	24.0	101.0	105.0	25.0	2.0	3.0	54.0	41.0	14.0	390.0
1898 [1]	11.0	8.0	16.0	33.0	18.0	70.0	62.0	3.0	2.0	.5	2.0	6.0	231.5
1899	[1] 10.0	[1] 8.0	[1] 18.0	[1] 14.0	[1] 5.0	[1] 2.0	[2] 2.0	[2] 1.0	[2] 2.0	[2] 2.0	[2] 9.0	[2] 10.0	83.0
1900 [2]	7.0	9.0	10.0	7.0	24.0	45.0	1.0	1.0	.3	.2	1.0	10.0	115.5
1901 [2]	10.0	9.0	12.0	6.0	32.0	21.0	2.0	1.0	.5	.5	1.0	5.0	100.0
1902 [2]	6.0	6.0	10.0	6.0	5.0	3.0	1.0	1.0	.2	.1	.4	1.0	39.7
1903 [2]	.3	1.0	1.0	7.0	32.0	268.0	37.0	1.0	2.0	1.0	1.0	4.0	358.3
1904 [2]	3.0	4.0	3.0	3.0	1.0	2.0	1.0	2.0	6.0	73.0	10.0	11.0	119.0
1905 [2]	14.0	12.0	33.0	18.0	209.0	318.0	8.0	3.0	1.0	2.0	7.0	9.0	634.0
1906 [2]	10.0	10.0	11.0	17.0	84.0	158.0	48.0	17.0	15.0	41.0	31.0	20.0	462.0
1907 [2]	21.0	19.0	28.0	46.0	80.0	299.0	240.0	76.0	53.0	24.0	18.0	14.0	918.0
1908	[1] 5.0	[1] 6.0	[2] 24.0	[2] 14.0	[2] 8.0	[2] 22.0	[2] 9.0	[2] 23.0	[2] 10.0	[2] 11.0	[2] 8.0	[2] 9.0	149.0
1909 [2]	12.0	12.0	17.0	24.0	91.0	166.0	18.0	15.0	107.0	38.0	23.0	17.0	540.0
1910 [2]	16.0	13.0	46.0	47.0	86.0	19.0	2.0	1.0	.5	3.0	7.0	11.0	251.5
1911 [2]	15.0	14.0	13.0	10.0	34.0	143.0	159.0	21.0	27.0	148.0	33.0	20.0	637.0
1912	[2] 21.0	[2] 18.0	[2] 21.0	[2] 19.0	[2] 133.0	186.0	40.0	9.0	4.8	10.5	15.4	[2] 11.0	488.7
1913	[1] 6.0	[1] 8.0	[1] 14.0	[2] 22.0	11.3	25.0	1.4	.4	1.7	23.6	19.2	[1] 8.0	140.6
1914	[1] 10.0	[1] 12.0	[2] 18.0	[2] 14.0	52.3	115.0	39.3	28.4	30.5	31.9	15.3	[1] 12.0	378.7
1915	10.6	10.9	16.5	15.7	36.0	67.2	20.0	12.7	12.7	12.4	15.0	14.1	245.8
1916	17.5	18.8	30.8	15.5	50.8	40.6	10.7	59.8	11.5	74.4	54.0	[1] 20.0	404.4
1917	[1] 18.0	[1] 14.0	[1] 18.0	18.1	41.0	217.0	92.8	10.1	5.8	7.8	16.8	14.0	[illegible]
1918	11.4	12.2	18.5	5.7	3.8	6.8	4.9	.8	15.8	4.3	12.7	14.3	111.2
1919	11.7	10.6	19.5	53.5	123.0	30.3	16.8	11.0	1.9	5.9	16.8	17.2	318.2
1920	15.8	16.9	19.9	20.2	113.0	248.0	58.6	7.5	5.9	14.4	23.0	17.2	560.4
1921	15.7	14.7	29.0	12.7	43.9	333.0	59.9	39.7	29.2	18.7	20.8	18.9	636.2
1922	20.6	17.7	20.5	13.1	99.6	130.0	21.0	1.8	1.1	1.3	12.7	15.6	355.0
1923	14.7	17.1	19.6	14.8	16.0	49.8	20.6	29.6	37.9	57.2	36.7	24.5	338.5
1924	16.0	16.1	17.9	63.1	119.0	37.5	6.0	1.4	1.1	2.0	10.8	13.0	303.9
1925	9.2	11.2	25.3	10.3	6.1	8.2	4.0	5.8	14.4	18.8	22.3	20.9	156.5
1926	16.6	15.6	21.0	15.5	18.1	41.1	5.2	.9	.8	1.7	11.5	15.4	163.4
1927	10.8	15.6	17.4	13.6	9.3	51.4	87.9	[illegible]	[illegible]	[illegible]	27.7	[illegible]	407.1

[1] Estimated by reference to estimated flow of Rio Grande at Lobatos, from monthly relation curves. (See table 131.)
[2] Same as footnote 1, except reference is to measured flow at Lobatos.

TABLE 130.—*Run-off of Rio Grande at Alamosa, Colo.*—Continued

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1928	17.8	17.3	[illegible]	[illegible]	[illegible]	23.3	3.1	2.2	1.3	[illegible]	10.1	11.7	152.9
1929	11.6	[illegible]	16.4	14.8	18.2	35.8	3.9	50.1	59.4	40.6	29.2	19.8	310.9
1930	12.9	17.8	14.6	7.6	5.2	3.3	7.6	3.5	1.0	1.4	7.7	8.3	90.9
1931	7.7	12.5	16.9	[illegible]	1.7	3.3	2.9	1.5	1.2	.9	3.6	11.0	65.6
1932	10.5	12.5	[illegible]	3.3	24.8	63.7	24.1	2.5	1.9	1.9	11.5	15.1	190.1
1933	12.3	[illegible]	10.1	.7	2.0	7.0	[illegible]	2.3	1.3	1.0	[illegible]	[illegible]	[illegible]
1934	10.7	13.1	[illegible]	[illegible]	2.2	3.0	[illegible]	1.7	1.0	[illegible]	[illegible]	[illegible]	48.9
1935	7.3	[illegible]	.9	[illegible]	3.2	50.0	[illegible]	1.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mean	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	82.4	[illegible]	11.3	12.8	[illegible]	[illegible]	[illegible]	[illegible]
Percent of annual	[illegible]	[illegible]	[illegible]	6.49	16.22	28.74	[illegible]	[illegible]	4.46	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]
[illegible]
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 131.—*Run-off of Rio Grande near Lobatos, Colo.*

[illegible]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in percent of mean
1890 [1]	13.0	[illegible]	27.0	[illegible]	[illegible]	171.0	65.0	[illegible]	16.0	19.0	[illegible]	[illegible]	689.0	125.2
1891 [1]	25.0	[illegible]	38.0	[illegible]	246.0	213.0	101.0	34.0	13.0	80.0	35.0	[illegible]	918.0	[illegible]
1892 [2]	18.0	22.0	45.0	113.0	[illegible]	[illegible]	16.0	[illegible]	1.0	[illegible]	4.0	[illegible]	560.0	101.8
1893	4.0	8.0	19.0	51.0	[illegible]	103.0	1.0	1.0	4.0	1.0	[illegible]	[illegible]	327.0	59.4
1894	[2] 3.0	[2] 2.0	[2] 27.0	[illegible]	[illegible]	[2] 15.0	[2] 1.0	[2] 1.0	[2] 1.0	[2] 25.0	[2] 2.0	[2] 10.0	215.0	[illegible]
1895 [2]	16.0	14.0	31.0	92.0	106.0	[illegible]	[illegible]	[illegible]	22.0	15.0	24.0	21.0	[illegible]	102.1
1896 [2]	21.0	19.0	41.0	65.0	58.0	[illegible]	[illegible]	[illegible]	[illegible]	7.0	8.0	14.0	247.0	44.9
1897 [2]	9.0	[illegible]	21.0	62.0	[illegible]	[illegible]	[illegible]	[illegible]	7.0	74.0	[illegible]	22.0	735.0	133.5
1898 [2]	17.0	12.0	28.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.0	6.0	10.0	518.0	94.2
1899	[2] 16.0	[illegible]	[2] 31.0	[2] 37.0	[illegible]	[illegible]	[illegible]	[illegible]	6.1	7.2	15.4	[illegible]	180.3	32.8
1900	12.3	13.9	[illegible]	20.2	[illegible]	108.0	1.2	[illegible]	1.2	1.7	3.3	16.9	303.8	55.2
1901	15.1	13.9	22.3	16.8	[illegible]	66.0	5.0	3.4	2.6	3.0	2.1	9.2	283.7	51.6
1902	[illegible]	8.9	18.8	18.3	[illegible]	[illegible]	.7	.6	1.0	1.3	1.1	1.7	[illegible]	18.0
1903	[illegible]	1.4	2.1	18.7	124.0	379.0	72.4	[illegible]	5.4	3.9	8.3	7.4	627.0	114.0
1904	7.1	[illegible]	6.8	9.1	1.3	[illegible]	1.1	8.6	11.7	97.8	17.9	[illegible]	187.6	34.1
1905	21.5	18.0	55.2	46.0	350.0	430.0	16.7	[illegible]	3.8	6.3	13.6	[illegible]	986.5	[illegible]
1906	16.6	15.0	20.9	45.3	205.0	260.0	[illegible]	[illegible]	25.2	56.8	45.4	30.7	842.2	153.1
1907	[illegible]	29.2	[illegible]	117.0	201.0	411.0	334.0	107.0	73.2	35.4	[illegible]	22.0	1,436.5	[illegible]
1908	[4] 9.0	[4] 8.0	41.7	37.4	47.0	68.4	[illegible]	38.4	[illegible]	17.8	11.9	11.8	335.0	61.0
1909	18.4	19.1	30.1	63.1	213.0	269.0	37.3	28.7	140.0	53.4	33.9	27.1	[illegible]	169.6
1910	24.0	19.7	76.2	121.0	207.0	60.1	2.0	4.6	[illegible]	7.4	13.6	17.8	[illegible]	101.0
1911	22.8	21.1	23.1	27.4	129.0	243.0	222.0	35.6	41.6	193.0	47.6	30.7	1,036.9	[illegible]
1912	30.6	28.0	36.7	50.0	262.0	306.0	49.5	17.3	11.7	17.4	21.6	[illegible]	849.2	154.4
1913	[illegible]	[4] 12.0	[5] 25.0	57.1	50.5	52.7	4.9	2.3	4.1	23.6	24.0	[2] 14.0	281.2	51.1
1914	[illegible]	[2] 18.0	31.6	38.5	102.0	155.0	48.4	43.7	48.6	45.1	25.5	[4] 19.0	591.4	107.4
1915	18.0	[illegible]	24.5	49.0	102.0	125.0	39.7	26.1	[illegible]	15.6	19.5	[illegible]	471.0	[illegible]
1916	22.6	26.2	47.8	[illegible]	164.0	114.0	37.7	83.8	25.5	94.1	65.5	[2] 32.0	764.5	138.9
1917	[2] 27.0	[2] 22.0	[4] 31.0	[illegible]	[illegible]	296.0	157.0	17.6	9.5	12.1	22.4	22.0	[illegible]	[illegible]
1918	17.3	[illegible]	33.0	[illegible]	28.1	52.2	21.1	3.2	22.5	10.5	19.7	19.7	[illegible]	47.7
1919	16.8	[illegible]	34.6	120.0	[illegible]	63.7	35.7	20.3	7.1	12.2	[illegible]	23.6	612.2	[illegible]
1920	23.1	[illegible]	[illegible]	32.0	[illegible]	408.0	[illegible]	22.1	17.0	23.2	37.4	33.3	[illegible]	[illegible]
1921	30.7	26.7	[illegible]	[illegible]	[illegible]	389.0	57.4	[illegible]	41.3	27.6	31.4	26.8	862.9	[illegible]
1922	20.6	28.7	33.0	[illegible]	197.0	258.0	41.0	5.9	4.9	[illegible]	[illegible]	24.1	673.9	122.4
1923	23.1	[illegible]	27.7	[illegible]	[illegible]	160.0	28.6	43.0	61.3	[illegible]	59.5	40.3	696.5	[illegible]
1924	24.0	[illegible]	[illegible]	[illegible]	329.0	81.5	[illegible]	4.6	4.2	7.6	17.2	20.9	753.0	137.0
1925	16.0	26.0	[illegible]	32.1	[illegible]	17.7	[illegible]	18.4	23.4	33.0	35.1	35.2	323.0	[illegible]
1926	[illegible]	30.0	38.8	43.4	[illegible]	107.0	14.7	3.7	3.7	5.0	16.6	23.2	425.7	77.4
1927	19.7	27.0	26.7	26.5	[illegible]	118.0	128.0	16.8	109.0	84.8	43.8	27.0	723.8	131.5
1928	24.2	[illegible]	39.2	27.7	94.1	[illegible]	2.6	3.4	4.1	4.6	17.9	22.1	325.4	59.1
1929	16.8	15.7	28.0	27.3	120.0	[illegible]	10.3	76.2	80.9	55.8	[illegible]	31.7	597.8	108.7
1930	18.6	21.3	[illegible]	[illegible]	38.0	33.0	11.9	16.3	5.5	9.0	15.6	[illegible]	270.4	49.2
1931	12.0	17.1	32.2	14.0	[illegible]	[illegible]	1.3	2.0	3.2	[illegible]	6.9	17.0	125.5	22.8
1932	[illegible]	21.7	[illegible]	28.4	168.0	170.0	86.7	11.0	[illegible]	11.0	[illegible]	21.0	596.4	[illegible]
1933	[illegible]	13.9	28.7	11.1	33.0	75.6	[illegible]	2.8	[illegible]	[illegible]	[illegible]	20.5	237.0	43.1
1934	20.0	22.2	16.5	[illegible]	6.7	1.8	.7	1.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1935	12.6	13.0	[illegible]	[illegible]	[illegible]	166.0	48.7	[illegible]	[illegible]	[illegible]	16.3	[illegible]	[illegible]	[illegible]
Mean	17.9	18.5	31.4	[illegible]	[illegible]	[illegible]	47.4	19.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
Percent of annual	3.25	3.36	5.70	[illegible]	[illegible]	[illegible]	[illegible]	3.62	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

[illegible]

TABLE 132.—*Run-off of Clear Creek below Continental Reservoir, Colo.*

[Drainage area, [illegible] square miles. Unit, acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1929					7,930	4,630	6,460	3,600	2,160	1,780	1,190	806	
1930	[illegible]	[illegible]	¹615	3,270	5,870	4,210	3,446	2,530	1,260	1,080	[illegible]	¹615	24,792
1931	[illegible]	[illegible]	¹615	²1,190	3,250	2,400	1,170	[illegible]	738	781	²625	¹615	13,156
1932	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5,130	3,830	[illegible]	[illegible]	676	[illegible]	[illegible]	21,998
1933	[illegible]	[illegible]	[illegible]	928	[illegible]	[illegible]	2,560	1,380	1,110	[illegible]	¹476	[illegible]	20,246
1934	[illegible]	[illegible]	[illegible]	3,760	3,180	1,080	1,030	[illegible]	[illegible]	[illegible]	¹476	[illegible]	13,029
1935	¹492	¹444	¹492	1,010	4,620	3,170	1,880	2,230	1,090	[illegible]	¹595	¹615	17,271

¹ Estimated.
² Partially estimated.

Records from May 1929 to September 1934 from biennial reports of the Colorado State engineer.
Records from October 1934 to December 1935 are provisional records furnsihed by U. S. Geological Survey.

TABLE 133.—*Run-off of South Fork Rio Grande at South Fork, Colo.*

[Drainage area 216 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1910								(¹)	2.4	3.6	[illegible]	²2.5	
1911	²2.2	²1.8	²4.0	15.5	50.3	71.9	41.4	10.4	8.6	(¹)	8.4	[illegible]	
1912	²3.6	²2.9	²4.2	8.8	57.0	64.7	19.3	5.6	3.2	4.6	5.2	²2.8	[illegible]
1913	²2.0	²2.1	²2.6	²17.2	36.9	33.0	7.1	3.6	4.6	5.5	4.2	2.3	121.1
1914				11.0	37.5	49.3	17.4	[illegible]	8.9	12.4	[illegible]	2.1	
1915	2.0	3.3	5.0	11.8	27.9	56.1	18.3	6.8	3.9	3.5	2.7	2.5	143.8
1916	[illegible]	3.1	7.9	18.9	53.1	73.2	27.1	12.7	8.6	[illegible]	(¹)		
1917				12.6	31.4	100.0	[illegible]	9.7	5.1	3.2	2.8	[illegible]	
1918	1.9	1.9	4.3	8.9	29.4	42.7	12.8	6.2	5.5	2.8	3.5		
1919				18.8	53.4	[illegible]	17.1	7.8	3.8	3.5	4.1	3.7	
1920				8.3	73.2	101.0	35.3	8.5	3.6	3.4	3.5	3.1	
1921	[illegible]	2.6	7.3	9.2	[illegible]	72.0	20.2	12.1	7.1	3.0	2.1		
1922				12.5	73.2	83.9	18.3	7.3	2.5				

¹ Partial record.
² Estimated.

Records previous to October 1913 as published in U. S. Geological Survey Water Supply Paper No. 358.
Records from October 1913 to September 1922 from biennial reports of the Colorado State engineer.
Station reestablished in 1936. See U. S. Geological Survey records for 1936.

TABLE 134.—*Run-off of Pinos Creek, near Del Norte, Colo.*

[Drainage area 62 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1919				¹3.2	8.4	5.6	4.1	1.7	1.0	0.7	0.7		
1920			(²)	1.3	14.0	20.2	5.5	1.6	.7	.7			
1921				1.1	6.5	8.1	[illegible]	2.7	1.8	.8			
1922				1.5	13.5	18.7	[illegible]	1.1	.6	[illegible]			
1923				1.5	8.4	8.2	2.9	2.3	1.9	[illegible]	¹.9		
1924				1.9	12.9	7.7	1.8	.8	.5				

¹ Estimated.
² Partial record.

Records from biennial reports of the Colorado State engineer.

TABLE 135.—*Run-off of Rock Creek near Monte Vista, Colo.*

[Drainage area 38 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1919				2.5	4.5	2.6	2.0	1.0	0.4	0.4	0.5		
1920			0.4	[illegible]	[illegible]	[illegible]	1.8	1.0	.4	.4			
1921				.5	1.8	2.0	.8	.8	.4	.2			
1922				.5	3.1	2.5	1.0	.8	.4	.3			
1923					2.8	2.0	1.3	.9	.9	.9			
1924				[illegible]	3.8	1.8	.7	.3	.2				
1925					3.2	3.3	1.0	.8	.4	.2			

¹ Partial record.
² Partially estimated.

Records from April 1919 to September 1924 from biennial reports of the Colorado State engineer.
Records from May 1925 to October 1925 are provisional records furnished by the Colorado State engineer.

TABLE 136.—*Run-off of Alamosa Creek above Terrace Reservoir, Colo.*

[Drainage area 102 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
[illegible]				[illegible]	[illegible]	[illegible]	11.2			3.9	[illegible]	[illegible]	
[illegible]				11.4	[illegible]	[illegible]	5.8	6.6	1.7				
[illegible]				7.2	28.6	40.7	21.4	7.4	7.2	18.4			
[illegible]		3.0	3.4	4.1	33.6	33.4	21.8	[illegible]	3.2	(2)			
[illegible]				6.1	17.6	34.9	14.5	4.9	2.5	1.9			
[illegible]				[illegible]	[illegible]	35.5	13.5	9.5	3.8	5.8			
[illegible]		1.1	1.2	5.3	18.8		28.5	7.3	2.9	1.3			
1918			2.1	3.4	18.8	24.3	10.2	4.1					
[illegible]				9.3	34.1	22.9	12.4	5.6	2.0	1.0			
[illegible]										[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[2]2.7	[illegible]	7.8	35.9	24.8	6.4	2.7	1.4				
[illegible]			[illegible]	9.9	27.9	19.9	9.4	5.4	3.5	3.1	(3)		
[illegible]				4.3	23.1	27.3	8.9	4.2	[illegible]				
1927				7.0	32.3	32.0	14.5	5.7	8.3				
[illegible]										1.0	.7		
1935				3.9	12.8	[illegible]	20.3	7.0	2.4	1.6	[illegible]		

[illegible]

Records previous to October 1912 as published in U. S. Geological Survey Water Supply Paper No. 358.
Records from April 1915 to September 1927 from biennial reports of the Colorado State engineer.
Records from October 1934 to November 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 137.—*Run-off of Alamosa Creek below Terrace Reservoir, Colo.*

[Drainage area 120 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
[illegible]		[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
[illegible]													
[illegible]		[illegible]	[illegible]	1.2	6.6	58.1	36.0	10.6	2.8	1.4	[illegible]		
[illegible]			2.1	3.4	18.8	24.9	9.5	[1]4.0					
1919					26.8	26.3	12.4	5.7	2.1	1.3			
[illegible]					27.1	52.8	29.1	12.0	1.7	2.5			
1921													
[illegible]				5.2	28.5	37.3	13.0	7.2	3.3	[illegible]	[3]1.5	[3]1.5	
[illegible]	[illegible]	[3]1.4	[3]1.5	3.1	29.0	[illegible]	17.5	6.8	6.1	[illegible]		[illegible]	107.8
[illegible]	[3]3.8	[3]3.6	[3]3.8	8.2	35.7	32.1	10.4	4.8	1.4	1.0	1.2	[3]1.2	107.2
[illegible]	[3]1.3	[3]1.2	[illegible]	9.5	23.8	18.4	10.3	5.7	3.5	2.9	[illegible]		
[illegible]				3.2	17.8	[illegible]	11.3	7.9	2.2	1.0		[illegible]	
[illegible]	[3].6	[3].6	[illegible]	6.8	[illegible]	20.4	[illegible]	9.5	4.5	5.7	[illegible]		
[illegible]				4.5	17.8	[illegible]	9.2	7.0	1.7	1.1	[illegible]	[3].4	
1929	[3].4	[3].4	.7	7.5	24.5	30.2	15.0	[illegible]	7.1	4.8	[3]3.3	[3]2.9	107.4
[illegible]	[2]2.8	[illegible]	[illegible]	[illegible]	17.5	19.0	[illegible]	9.1	2.8	2.1	[illegible]	[3]1.2	72.9
1931	[3]1.2	[illegible]	[illegible]	[illegible]	11.7	13.1	3.9	2.9	4.9	5.0	[3].9	[3].9	49.7
[illegible]	[3].9	[3].9	[illegible]	[illegible]	25.6	33.0	[illegible]	[illegible]	[illegible]	2.8	[3]1.8	[3]1.1	118.7
1933	[3].9	[3].8	[illegible]	[illegible]	14.6	29.0	11.3	6.5	1.9	[illegible]	[3].9	[3].6	70.8
1934	[3].6	[3].7	[illegible]	[illegible]	11.4	2.7	1.5	1.8	1.3		.6	.4	36.2
[illegible]		[3].5	[2]1.1	4.5	12.3	38.3	20.8	12.0	[illegible]	2.3	2.1	2.2	[illegible]

[1] Partial record.
[2] Partially estimated.
[3] Estimated.

Records from April 1915 to September 1934 from biennial reports of the Colorado State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 138.—*Run-off of La Jara Creek near Capulin, Colo.*

[illegible]

[illegible]	January	February	March	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1916				3.7	7.0	3.5	3.9	1.3	[illegible]	0.7			
[illegible]				3.8	5.8	3.1	1.8	1.1	1.1	1.1	0.8		
[illegible]													
[illegible]				6.1	5.7	6.0	3.5	.8	.7	.7	.8		
[illegible]				[illegible]	10.8	3.4	3.7	3.2	[illegible]	[illegible]	.9		
[illegible]				[1]1.8	[illegible]	[illegible]	[illegible]	.8	.6	[illegible]			
[illegible]				[illegible]	[illegible]	[illegible]	5.8	1.4	[illegible]				
[illegible]				[illegible]	[illegible]	[illegible]	5.1	2.4	1.7	1.1	1.2		
[illegible]					[illegible]	2.7	1.8	1.7	1.0	.9	[illegible]		
[illegible]			[4]1.0	3.9	3.4	1.0	.9	[illegible]	.4	.4	[4].2		
[illegible]					4.7	4.2	2.2	.6	.4	.4			
[illegible]				3.3	4.7	[illegible]	1.4	.9	.9	.8			
[illegible]				2.4	3.3	1.1					[4].4		
[illegible]				4.1	4.8	[illegible]			[illegible]	.6			
[illegible]							1.7	1.1	.7				
[illegible]													
[illegible]				[illegible]	[illegible]	[illegible]	.4		[illegible]	.5			
[illegible]			(2)	.9	2.6	[illegible]	1.0	2.2	.4		[illegible]		
[illegible]			[illegible]	1.2	[illegible]	[illegible]	.5	.3	.2	.3	.2	[illegible]	
[illegible]				1.6	[illegible]	[illegible]	.3	.3	.3	.4			

[illegible]

Records from April 1916 to September 1934 from biennial reports of the Colorado State engineer.
[illegible]

TABLE 139.—*Run-off of La Jara Creek near mouth, Colo.*

[Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1924										¹1.[illegible]	¹1.9	²2.3	
1925	[illegible]	[illegible]	²3.4	2.8	1.5	0.7	1.6	3.6	[illegible]	1.7	[illegible]	²2.5	[illegible]
1926	²1.8	[illegible]	²4.3	4.6	4.3	3.1	1.9	.8	1.1	.7	1.7	²1.5	27.7
1927	²2.0	[illegible]	²2.8	²1.0	1.0	2.7	2.3	3.9	4.4	[illegible]	3.7	²3.2	31.3
1928	[illegible]	[illegible]	²3.7	2.0	3.8	1.2	.3	.3	.6	.3	1.1	²1.7	[illegible]
1929	[illegible]	[illegible]	²3.7	3.1	4.2	2.0	2.1	4.7	5.0	¹2.5	²4.2	²4.0	[illegible]
1930	[illegible]	²3.3	3.8	2.6	1.0	.3	.8	1.9	.6	2.3	²2.1	[illegible]	23.3
1931	²1.5	²1.9	²3.1	[illegible]	.2	0	0	0	0	1.3			
1932				2.7	5.6	4.2	3.9	1.2	1.1				

¹ [illegible]
² [illegible]

Records from biennial reports of the Colorado State engineer.

TABLE 140.—*Run-off of Trinchera Creek above Turners Ranch, near Fort Garland, Colo.*

[Drainage area [illegible] square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1923				0.6	2.7	3.6	1.5	1.4	1.3	1.3	1.1		
1924					7.8	7.6	2.5	.8	.7	¹.7	.5		
1925				1.6	2.3	1.6	1.0	.8	.6	.6			
1926					[illegible]	9.1	2.9	1.3	.7	1.0	¹1.0		
1927				1.0	3.8	3.4	1.7	1.0	.8	1.0	³.6	¹0.4	
1928	¹0.3	¹0.2	³0.6	1.3	5.6	5.8	1.9	1.2	.9	.9	.7		
1929				.9	3.2	3.0	1.1	1.8	1.0	.9	.6		
1930				1.7	3.2	3.5	1.6	2.7	1.2	.8	³.7		
1931			³.4	.8	2.4	3.2	1.4	.7	.7	1.0	³.7		
1932				1.9	6.1	³4.8	2.3	1.2	.8	.7	[illegible]		
1933			(²)	.7	3.8	7.6	2.4	1.0	.6	.6	[illegible]		
1934				1.4	2.4	1.4	.8	.7	.5	.5			
1935			[illegible]	.8	2.7	7.7	2.4	1.2	.8	³.8			

¹ Estimated.
² Partial record.
³ Partially estimated.

Records from April 1923 to September 1934 from biennial reports of the Colorado State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 141.—*Run-off of Trinchera Creek above Mountain Home Reservoir near Fort Garland, Colo.*

[Drainage area [illegible] square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1923					1.4	2.3	0.7	0.9	1.0	0.8	[illegible]		
1924				¹1.4	6.3	3.9	1.2	.4	.4	.2	.4		
1925			[illegible]	.3	.9	[illegible]	.6	.6	.3	.1	.3		
1926				.6	6.8	10.[illegible]	2.4	.9	[illegible]	.4	.3		
1927				.7	2.5	2.2	1.3	1.0	[illegible]	.8	.6		
1928				.7	5.5	5.3	1.3	.8	[illegible]	.2	.2		
1929				.4	2.4	2.5	1.1	1.4	1.1	.9	[illegible]		
1930				.8	1.9	2.5	2.0	3.2	1.3	.8	[illegible]		
1931				³.6	¹1.7	2.5	1.1	.8	.6	.8	¹.5		
1932			¹0.6	1.7	5.3	3.8	1.5	.8	.6	.6			
1933				.7	3.3	7.6	2.0	.8	.6	.6	[illegible]		
1934				.8	1.7	1.3	.6	.5	.5	.5			
1935				.4	1.8	5.6	2.0	1.2	.7	.9			

¹ Partially estimated.
² Partial record.
³ Estimated.

Records from May 1923 to September 1933 from biennial reports of the Colorado State engineer.
Records from October 1933 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934, to October 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 142.—*Run-off of Trinchera Creek below Smith Reservoir near Blanca, Colo.*

[Drainage area 396 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1928										0.1	[illegible]		
1929				0.9	1.6	0.7	0.6	0.4	0.1	.1			
1930				1.9	.2	.7	.6	.3	.1	.1	[illegible]	¹0.1	
1931	¹0.1	¹0.1	[illegible]	1.7	3.2	1.0	.8	.2	.1	.1	[illegible]		
1932			1.6	6.7	7.3	.7	1.1	.7	.1	.1	[illegible]		
1933				1.1	4.0	1.9	.5	.5	.1	.1	[illegible]	¹.1	
1934	¹.1	.2	1.6	2.6	.1	.3	.2	.1	.1	.1	[illegible]	.1	[illegible]
1935	.0	.0	.0	[illegible]	.5	1.6	.3	.7	.1	.1			

¹ [illegible]
³ Partially estimated.

Records from October 1928 to September 1933 from biennial reports of the Colorado State engineer.
Records from October 1933 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to October 1935 are provisional records furnished by U. S. Geological Survey.

Table 143.—*Run-off of Sangre de Cristo Creek near Fort Garland, Colo.*

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	May	[illegible]	July	August	[illegible]	October	[illegible]	[illegible]	[illegible]
[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	0.5	[illegible]	[illegible]			
[illegible]					[illegible]	[illegible]	[illegible]		[illegible]	.1	1.2		
[illegible]				[illegible]	[illegible]	5.5	[illegible]		.2	.9	.9		
[illegible]				[illegible]	1.7	3	.3		.1		.3		
[illegible]				4.8	13.8	5.2	1.7	[illegible]	.3	[illegible]			
[illegible]				3.2	3.3	1.2	.8		.4	.6			
[illegible]				2.0	11.5	4.1	1.0	.6	.1	.4			
[illegible]				[illegible]	4.9	1.6		.7	.5				
[illegible]													
[illegible]										.5	[illegible]		
[illegible]				[illegible]	9.4	2.6	.9		.1	.6			
[illegible]				[illegible]	[illegible]	4.6	1.2	.5	.5	[illegible]	[illegible]		
[illegible]				[illegible]	1.5	.3	.1		.0				
[illegible]				[illegible]	[illegible]	2.8	.6	[illegible]	[illegible]	[illegible]			

[illegible]

Records from October 1933 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to October 1935 are provisional records furnished by U. S. Geological Survey.

Table 144.—*Run-off of Ute Creek near Fort Garland, Colo.*

[Drainage area 32 square miles. Unit, 1,000 acre-feet]

[illegible]	January	February	[illegible]	April	[illegible]	June	July	August	[illegible]	October	[illegible]	December	Annual
[illegible]							2.4	1.1	1.6	1.2	1.0	[illegible]	
[illegible]	0.4	0.6	0.7	[illegible]	1.8	[illegible]	[illegible]	1.4	.7	.7	.7	.4	[illegible]
[illegible]	.3	.3	.6	1.0	3.3	[illegible]	[illegible]	1.5	2.5	.9	.8		
[illegible]				[illegible]	(3)	[illegible]	[illegible]	[illegible]	(3)	[illegible]			
[illegible]					2.3	[illegible]	[illegible]	2.1	1.6	[illegible]	[illegible]		
[illegible]				[2] 3.3	6.6	[illegible]	[illegible]	.8	.5	.6	.5		
[illegible]				1.2	1.4	1.0	[illegible]	1.2	.7	.6	.7		
[illegible]				[illegible]	4.7	[illegible]	1.7	[illegible]	.4	.3	[2] .3		
[illegible]				1.5	3.7	2.9	2.8	2.3	1.5	1.0	.7		
[illegible]				1.0	4.2	3.5	1.7	1.7	.6	.5	.6		
[illegible]				1.3	4.0	4.0	3.0	3.5	2.6	[illegible]	1.0		
[illegible]				2.2	2.1	2.6	2.4	2.0	.4	[illegible]	[2] .5		
[illegible]				1.4	4.1	4.6	1.7	.6	[illegible]	[illegible]	[1] .8		
[illegible]			[illegible]	4.0	6.3	4.8	4.0	1.9	.8	.7			
1933			[illegible]	.8	2.1	4.1	1.4	1.7	1.2	.6	[illegible]		
[illegible]				[illegible]	2.4	.7	.5	.5	.7	.4			
[illegible]				.6	1.8	6.7	2.9	1.8	.9	.9			

[illegible]

Records from October 1934 to October 1935 are provisional records furnished by U. S. Geological Survey.

Table 145.—*Run-off of Conejos River near Mogote, Colo.*

[Drainage area, 282 square miles. Unit, 1,000 acre-feet]

Year	January	Febru-[illegible]	[illegible]	[illegible]	[illegible]	June	July	[illegible]	Septem-[illegible]	October	Novem-ber	[illegible]	Annual	Annual run-off in percent of mean
[illegible]	2.4	2.1	6.2	23.0	110.0	93.0	[illegible]	[illegible]	[illegible]	[illegible]	4.3	3.5	301.5	118.0
[illegible]	[illegible]	[illegible]	6.1	[illegible]	[illegible]	101.0	[illegible]	[illegible]	[illegible]	[illegible]	4.6	[illegible]	311.5	[illegible]
[illegible]	[illegible]	[illegible]	4.8	26.0	[illegible]	55.0	16.0	9.0	2.8	2.7	3.4	2.0	193.4	[illegible]
[illegible]	[illegible]	[illegible]	4.1	[illegible]	50.0	45.0	7.0	7.0	3.0	2.8	3.4	2.0	140.8	55.1
[illegible]	[illegible]	[illegible]	[illegible]	23.0	61.0	29.0	6.5	8.0	1.2	4.5	3.8	2.6	150.9	59.0
1895	[illegible]	[illegible]	6.1	70.0	[illegible]	59.0	23.0	13.0	6.0	5.9	4.4	3.6	233.2	91.2
1896	[illegible]	[illegible]	6.8	[illegible]	63.0	25.0	7.0	6.0	7.0	6.0	4.0	2.6	171.3	[illegible]
[illegible]	2.5	2.1	6.2	27.0	90.0	83.0	25.0	9.0	9.0	25.0	7.0	4.8	290.6	113.7
[illegible]	[illegible]	[illegible]	[illegible]	47.0	[illegible]	106.0	38.0	10.0	4.0	2.8	[illegible]	2.0	296.1	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	30.0	15.0	11.0	4.8	6.0	5.0	2.3	133.6	[illegible]
[illegible]	[illegible]	[illegible]	4.1	10.0	73.0	67.0	11.0	5.0	2.7	4.4	3.5	[illegible]	[illegible]	[illegible]
[illegible]	2.2	1.8	3.8	18.0	66.0	50.0	12.0	9.0	6.0	2.8	3.8	2.0	177.4	[illegible]
[illegible]	1.8	[illegible]	3.9	16.0	30.0	[illegible]	[illegible]	4.0	[illegible]	2.6	3.2	1.8	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[2] 3.7	[1] 18.0	79.4	138.0	39.7	10.6	[illegible]	[illegible]	[2] 3.0	[1] 1.5	313.7	122.7
[illegible]	[illegible]	[illegible]	[2] 4.0	16.8	31.3	19.0	4.7	19.4	13.9	31.7	[2] 3.7	[2] 2.7	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[2] 6.2	17.7	94.9	132.0	32.5	13.1	5.2	4.4	4.1	[1] 2.3	317.7	124.3
[illegible]	[1] 2.0	[illegible]	[illegible]	[1] 23.0	82.4	[2] 127.0	[1] 44.0	[1] 14.0	[1] 11.0	[1] 14.0	[1] 6.0	[1] 3.6	333.6	[illegible]
[illegible]	[illegible]	[1] 3.0	[2] 10.0	28.9	[illegible]	109.0	[illegible]	[illegible]	[illegible]	6.5	1.9	1.6	[illegible]	[illegible]

[illegible]

TABLE 145.—*Run-off of Conejos River near Mogote, Colo.*—Continued

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off percent of mean
1908	¹2.2	[illegible]	[illegible]	13.0	31.7	[illegible]	[illegible]	17.7	7.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1909	²2.4	²2.5	²5.0	³19.0	75.0	[illegible]	33.7	19.3	27.7	[illegible]	[illegible]	[illegible]	[illegible]	126.3
1910	3.6	2.8	10.4	29.9	75.0	43.9	10.9	10.5	3.8	[illegible]	[illegible]	[illegible]	[illegible]	79.0
1911	3.4	2.5	5.0	21.6	[illegible]	123.0	70.1	20.5	17.1	[illegible]	[illegible]	¹5.0	105.7	158.7
1912	4.7	3.1	5.6	13.2	114.0	103.0	38.6	9.5	3.8	[illegible]	[illegible]	[illegible]	307.6	120.3
1913	2.6	2.4	3.4	[illegible]	56.0	48.7	12.1	4.1	3.9	[illegible]	3.2	¹4.8	[illegible]	61.6
1914	⁴2.9	⁴2.7	³7.0	17.7	[illegible]	80.3	28.1	18.9	17.0	13.1	4.4	[illegible]	253.2	99.1
1915	2.3	2.8	3.7	[illegible]	45.4	92.8	43.0	12.9	6.0	5.0	3.6	2.5	238.4	93.3
1916	2.4	3.0	5.2	21.7	90.4	129.0	50.2	24.0	10.8	20.4	7.5	⁴4.0	[illegible]	144.2
1917	⁴3.7	⁴3.4	[illegible]	19.4	46.4	138.0	76.2	15.4	5.4	3.1	2.6	1.9	[illegible]	125.4
1918	1.4	[illegible]	[illegible]	12.9	58.4	89.3	30.1	9.9	7.1	4.1	3.4	[illegible]	[illegible]	88.6
1919	2.7	[illegible]	[illegible]	29.5	[illegible]	61.9	31.4	10.8	[illegible]	4.4	3.8	3.9	[illegible]	96.4
1920	3.3	[illegible]	5.1	[illegible]	115.0	[illegible]	67.0	20.7	6.4	5.1	[illegible]	3.2	[illegible]	168.3
1921	[illegible]	3.2	7.1	10.9	63.3	106.0	31.3	19.3	6.6	3.9	3.1	2.5	260.1	101.8
1922	3.5	[illegible]	[illegible]	11.4	104.0	126.0	32.5	11.3	3.5	2.9	3.7	3.4	311.2	121.8
1923	3.0	[illegible]	4.9	22.0	121.0	127.0	42.2	23.4	19.7	17.5	6.2	5.3	[illegible]	154.3
1924	4.4	3.7	4.9	34.0	108.0	81.5	27.2	6.6	3.2	3.9	3.5	3.2	284.1	111.2
1925	3.0	3.0	5.4	[illegible]	71.9	[illegible]	20.7	14.9	8.5	11.2	6.8	3.9	233.2	91.2
1926	3.8	3.1	[illegible]	18.9	76.9	[illegible]	27.1	9.2	2.7	3.8	3.0	3.0	248.7	97.3
1927	2.7	1.9	3.9	24.2	95.9	99.4	[illegible]	16.6	28.8	14.6	8.4	4.4	344.3	134.7
1928	3.4	2.4	4.0	13.7	67.6	61.9	15.6	8.6	4.9	3.5	3.0	3.0	191.6	75.0
1929	2.8	2.7	5.5	[illegible]	101.0	97.0	30.6	32.8	27.1	10.1	4.5	2.5	339.9	133.0
1930	2.2	2.8	3.4	33.3	54.0	[illegible]	20.5	14.0	3.4	3.8	1.8	2.2	205.1	80.2
1931	1.8	1.8	3.1	11.7	38.1	[illegible]	9.6	9.2	12.7	13.2	4.3	4.3	150.6	58.9
1932	3.2	3.1	5.1	[illegible]	108.0	118.0	[illegible]	18.6	6.5	4.5	2.9	2.6	357.2	139.7
1933	2.8	2.2	4.4	9.7	44.4	93.4	27.2	11.3	8.3	7.1	3.9	2.5	217.2	85.0
1934	2.2	2.5	[illegible]	30.5	36.1	7.0	4.3	4.0	4.4	3.3	2.6	1.9	104.2	40.8
1935	1.9	2.4	4.3	15.1	45.3	135.0	56.8	17.9	8.6	5.8	3.6	2.4	299.1	117.0
Mean	2.7	2.5	5.2	21.7	71.1	84.3	30.7	13.2	8.4	[illegible]	[illegible]	[illegible]	255.6	
Percent of annual	1.06	[illegible]	[illegible]	[illegible]	27.82	32.98	12.01	5.16	3.29	[illegible]	[illegible]	1.21	100.0	

¹ Estimated by reference to Rio Grande near Del Norte from monthly relation curves.
² Estimated by reference to Rio Grande near Lobatos from monthly relation curves.
³ Partial record extended by reference to Rio Grande near Del Norte or Lobatos.
⁴ Estimate based upon relation of missing months to remaining months of the year as indicated by means for all complete years.

All records previous to October 1913 as published in U. S. Geological Survey Water Supply Paper no. 358 except as noted.
Records from October 1913 to September 1934 from biennial reports of the Colorado State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 146.—*Run-off of Conejos River near La Sauses, Colo.*

[Drainage area, 887 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1911	5.0	4.8	7.0	6.0	71.0	100.0	[illegible]	8.5	9.0	60.0	6.2	5.6	339.1
1912	7.0	[illegible]	9.0	2.0	125.0	70.0	10.0	1.5	.8	1.1	[illegible]	3.1	241.3
1913	3.8	4.5	3.0	1.4	25.0	10.0	.2	.2	.8	3.0	3.5	5.4	[illegible]
1914	4.3	[illegible]	12.0	[illegible]	38.0	39.0	[illegible]	[illegible]	9.0	9.0	4.9	3.5	137.6
1915	3.3	[illegible]	4.0	3.4	11.0	[illegible]	14.0	[illegible]	1.3	1.6	3.9	3.5	109.5
1916	3.5	6.0	8.0	5.5	80.0	109.0	24.0	11.0	3.5	20.0	7.5	4.0	282.0
1917	5.5	7.0	7.0	4.0	13.0	113.0	65.0	4.5	1.2	.9	2.5	3.1	[illegible]
1918	2.4	3.4	7.0	2.0	38.0	[illegible]	3.5	1.5	1.7	[illegible]	3.7	3.6	118.1
1919	4.0	5.7	7.0	19.0	72.0	20.0	4.0	2.0	1.3	1.4	4.2	4.1	141.7
1920	4.8	6.3	7.0	1.5	126.0	200.0	51.0	9.0	1.1	1.7	4.3	4.1	417.1
1921	¹4.3	¹6.5	²12.0	[illegible]	40.9	72.0	3.7	[illegible]	4.2	3.1	3.6	3.7	164.0
1922	¹5.2	¹7.3	5.4	6.4	110.0	[illegible]	7.7	.9	1.6	1.6	2.1	3.6	250.6
1923	3.7	[illegible]	3.7	7.7	109.0	101.0	8.9	11.7	14.9	[illegible]	9.5	6.0	295.7
1924	6.5	7.6	8.2	70.2	162.0	35.5	1.5	1.0	1.2	2.9	3.6	3.9	[illegible]
1925	3.8	5.4	[illegible]	13.9	27.2	6.4	.7	6.3	3.4	7.3	[illegible]	4.6	91.3
1926	4.7	5.0	5.8	19.2	84.2	53.3	3.7	1.2	1.4	1.4	2.0	3.1	185.0
1927	2.6	3.8	3.4	6.4	84.8	74.4	21.0	2.9	25.3	14.6	6.4	5.0	251.6
1928	5.0	5.4	6.0	6.0	52.3	26.6	.2	.3	.7	1.1	2.6	3.4	109.6
1929	3.3	4.5	5.1	6.8	94.7	45.7	1.4	18.8	18.2	2.5	6.2	4.9	212.1
1930	3.8	4.7	5.0	33.3	28.5	27.1	2.9	4.2	1.1	2.0	3.3	3.6	119.5
1931	3.5	5.3	6.8	4.0	3.6	.4	.1	.3	1.4	2.7	2.7	2.4	34.2
1932	3.6	6.7	8.6	11.8	123.0	101.0	38.9	.7	2.0	3.6	4.3	3.8	308.0
1933	3.9	4.2	4.8	1.2	24.8	58.8	1.6	.5	1.6	2.5	3.0	4.0	110.9
1934	4.6	4.3	3.4	1.2	.8	.1	.1	[illegible]	.5	1.1	1.8	[illegible]	20.8
1935	3.0	2.7	2.3	.8	42.8	110.0	26.4	1.7	2.3	3.3	3.7	4.0	203.0
Mean	4.2	5.3	6.3	9.6	63.5	63.1	14.0	4.2	4.4	6.6	4.3	4.0	189.5
Percent of annual	2.22	2.80	3.32	[illegible]	33.51	33.30	7.39	2.22	2.32	3.48	2.27	2.10	100.0

¹ Estimated by reference to run-off of Conejos River at Mogote and San Antonio River at mouth, from monthly relation curves.
² Partial record extended.

Records from March 1921 to September 1933 from biennial reports of the Colorado State engineer.
Records from October 1933 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 147.—*Run-off of San Antonio River at Ortiz, Colo.*

[illegible]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
[illegible]		0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
[illegible]													
1917													
1918													
[illegible]				[illegible]	[illegible]	[illegible]	1.7	.3	.6	.4			
[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	.6	.8	.1	[illegible]			
[illegible]													
[illegible]													
[illegible]										.1	[illegible]		
[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	.2	.3	[illegible]	[illegible]	.1		
[illegible]				8.2	11.4	[illegible]	.2	.2	.1	.1	.2		
[illegible]				7.7	11.0	1.7	.6	.2	[illegible]	.1			
[illegible]			[illegible]	4.2	[illegible]	[illegible]	[illegible]	[illegible]	.2	.1	[illegible]		
[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.1	.4			
[illegible]				[illegible]	[illegible]	.6	[illegible]	.5	.1	[illegible]			
[illegible]					[illegible]	.1	[illegible]	[illegible]	0		[illegible]		
[illegible]				[illegible]	18.8	1.9	.4	.3	.1	.3	[illegible]		
[illegible]				[illegible]	[illegible]	2.7	.5	.1	.1	.2	[illegible]		
[illegible]				[illegible]	.3	0	0	.1	.1	.1			
[illegible]				[illegible]	13.3	[illegible]	.3	.3	.2	[illegible]	.1		

[illegible]
[illegible]
[illegible]

[illegible]
Records from October 1933 to September 1934 from reports of U. S. Geological Survey
Records from October 1934 to November 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 148.—*Run-off of San Antonio River at mouth, near Manassa, Colo.*

[illegible]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
[illegible]	[illegible]	0.7	[illegible]	[illegible]	[illegible]	27.0	[illegible]	1.0	1.7	11.0	[illegible]	1.5	106.1
[illegible]	1.6	1.6	2.5	[illegible]	[illegible]	20.0	2.5	[illegible]	0	.3	1.1	0	96.8
1913 [1]	.3	.6	[illegible]	[illegible]	[illegible]	4.0	.3	[illegible]	0	[illegible]	[illegible]	1.4	26.7
[illegible]	.5	1.0	4.0	4.5	18.0	13.0	1.0	[illegible]	[illegible]	[illegible]	[illegible]	.2	47.7
1915 [1]	.1	1.1	1.0	[illegible]	9.0	17.0	3.0	.3	[illegible]	[illegible]	[illegible]	.2	37.7
[illegible]	[illegible]	1.4	2.1	[illegible]	44.0	29.0	5.0	1.6	[illegible]	[illegible]	[illegible]	1.0	97.7
[illegible]	[illegible]	[illegible]	2.0	[illegible]	[illegible]	[illegible]	13.0	.4	.1	[illegible]	.2	0	66.2
1918 [1]	[illegible]	0	1.9	[illegible]	18.0	16.0	1.0	.2	[illegible]	[illegible]	.5	.3	41.3
[illegible]	[illegible]	1.3	2.1	11.0	[illegible]	7.0	1.1	.2	.1	[illegible]	.7	.9	67.1
[illegible]	[illegible]	1.6	2.0	2.2	[illegible]	[illegible]	10.0	1.0	.1	[illegible]	.7	.6	132.3
[illegible]	[illegible]	1.7	4.0	2.6	22.0	21.0	1.1	[illegible]	.2	[illegible]	.4	.2	54.5
1922 [1]	.9	2.1	2.2	2.7	56.0	[illegible]	1.3	.2	[illegible]	[illegible]	.6	[illegible]	94.7
[illegible]	[illegible]	[illegible]	[illegible]	6.1	[illegible]	19.5	.9	1.3	3.7	3.7	2.1	1.5	87.4
1924	1.4	2.3	[illegible]	[illegible]	73.8	9.5	.6	[illegible]	[illegible]	[illegible]	.3	1.6	134.3
[illegible]	1.5	[illegible]	[1] 2.2	12.5	15.6	3.2	.6	[illegible]	.7	[illegible]	1.3	[illegible]	42.8
1926	.7	1.1	2.0	16.6	46.2	16.8	1.3	[illegible]	[illegible]	[illegible]	.3	.2	[illegible]
[illegible]	.3	.4	.4	7.0	52.2	26.2	5.4	.4	4.5	2.3	1.9	[illegible]	102.5
[illegible]	1.4	1.1	1.5	[illegible]	30.1	8.6	.3	[illegible]	[illegible]	.1	[illegible]	.1	[illegible]
[illegible]	0	.2	.5	7.4	[illegible]	10.9	[illegible]	1.1	3.1	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	.5	1.9	1.4	24.0	22.9	9.9	1.4	1.5	[illegible]	.3	.3	[illegible]	64.3
[illegible]	.1	.6	1.5	3.3	[illegible]	1.2	[illegible]	0	[illegible]	[illegible]	[illegible]	.6	15.1
1932	[illegible]	1.4	2.1	10.9	62.7	[illegible]	8.7	.2	.1	.4	[illegible]	.2	117.8
1933	.2	.2	.0	1.2	23.7	18.8	.6	.1	[illegible]	[illegible]	.2	.2	46.1
1934	[illegible]	[illegible]	[illegible]	[illegible]	2.1	.2	0	.0	[illegible]	0	0	[illegible]	5.4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36.6	32.3	1.1	.6	.4	[illegible]	.4	[illegible]	78.0
Mean	[illegible]	[illegible]	1.8	[illegible]	34.7	18.0	3.0	.7	.7	1.3	.7	.6	71.1
[illegible]	[illegible]	[illegible]	2.53	11.25	48.81	25.32	4.22	.98	.98	1.83	[illegible]	.84	100.0

[1] Estimated by reference to Conejos River at Mogote from monthly relation curves.

[illegible]
[illegible]
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 149.—*Run-off of Los Pinos River near Ortiz, Colo.*

[illegible]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.1	1.2		
[illegible]				[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	6.5		1.1	
1917					32.5	45.7	12.1	2.0	1.2	.8	.8		
[illegible]			[illegible]	9.1	34.4	19.3	5.1	1.4	1.1	1.0	1.2		
[illegible]				[illegible]	53.1	17.0	7.8	[illegible]	[illegible]	1.3	1.1		
[illegible]			[illegible]	8.5	[illegible]	45.8	9.5	2.7	.8	.8	.9		
[illegible]													
1922													
1923													

[illegible]

TABLE 149.—*Run-off of Los Pinos River near Ortiz, Colo.*—Continued

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1924										1.5	1.2		
1925				20.8	26.4	9.5	3.1	4.5	1.8	3.3	[2] 1.8		
1926				[illegible]	46.1	22.4	4.3	1.7	.9	1.0	1.1		
1927				12.0	56.9	26.4	7.0	2.6	[illegible]	3.7	[2] 2.1	[2] 1.1	
1928	[illegible]	[illegible]	[1] 1.8	9.3	38.6	13.2	2.8	1.5	1.0	.9	[illegible]		
1929				15.9	48.4	17.0	4.7	6.9	5.2	3.2	2.3		
1930			[illegible]	28.0	38.6	16.8	[illegible]	[2] 3.0	[2] 1.2	[2] 1.4			
1931			(1)	6.1	17.6	7.3	2.3	[illegible]	1.4	2.2	[illegible]		
1932			[2] 4.3	18.4	67.0	38.0	13.1	[illegible]	1.2	1.5			
1933				6.0	30.8	26.3	5.1	2.0	1.8	1.6	1.3		
1934				[illegible]	7.0	1.6	.8	.9	1.1	.9	.8		
1935				9.7	40.3	[illegible]	8.0	3.4	1.7	1.4			

[1] Estimated.
[2] Partial record.

Records from January 1915 to September 1933 from the biennial reports of the Colorado State engineer.
Records from October 1933 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to October 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 150.—*Run-off of Culebra Creek at San Luis, Colo.*

[Drainage area 220 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1909					8.7	11.5	7.6	7.9	8.5	5.0	3.0	1.8	
1910	2.4	2.1	6.1	7.7	11.8	6.7	1.8	3.3	2.2	2.2	2.3	1.8	50.4
1911	2.2	1.9	2.4	2.3	4.7	3.5	4.6	3.6	2.0	4.4	2.5	3.0	37.1
1912	2.6	2.7	2.3	2.7	10.0	11.6	9.6	4.0	2.3	2.7	2.4	2.5	55.4
1913	2.2	2.0	2.5	2.4	8.6	10.0	9.1	4.2	1.3	2.5	2.4	1.8	49.0
1914	1.7	1.6	2.2	1.7	4.2	15.8	8.8	4.6	2.5	2.9	2.9	2.6	51.5
1915	2.5	2.3	2.3	2.6	8.9	19.9	14.2	5.0	2.4	2.5	2.6	2.6	67.8
1916	2.4	2.5	3.4	3.3	10.6	18.4	7.5	5.1	2.8	2.6	2.3	2.2	63.1
1917	2.2	2.0	2.4	2.2	3.5	20.4	15.8	7.5	2.2	2.3	2.2	2.1	64.8
1918	2.1	1.9	2.2	1.9	8.9	7.1	11.3	5.6	3.4	3.0	2.0	2.1	51.5
1919	(1)	(1)	(1)	2.1	4.5	18.8	11.1	7.9					
1927				1.1	6.6	8.9	8.1	4.0	2.4	1.8	[2] 1.4	[2] 1.4	
1928	[2] 1.4	[2] 1.3	1.3	1.2	4.8	15.5	9.1	4.2	1.0	1.4	[2] 1.3	[2] 1.2	43.7
1929	[2] 1.1	[2] 1.1	[3] 1.2	.7	2.1	12.1	5.6	3.3	1.5	1.8	2.1	[3] 1.5	34.1
1930	[2] 1.2	[3] 1.1	1.3	1.2	8.4	11.3	6.0	5.5	2.7	1.8	[2] 1.6	[3] 1.5	43.6
1931	[2] 1.5	[2] 1.4	[2] 1.5	[2] 1.5	3.6	11.7	6.2	3.0	1.5	1.6	1.5	[3] 1.5	36.5
1932	[2] 1.5	[3] 1.4	[2] 1.4	1.4	2.4	8.4	7.6	5.5	2.2	1.8	1.7	1.7	37.0
1933	[2] 1.4	[2] 1.1	[2] 1.2	1.1	3.1	10.8	9.4	6.2	2.4	1.7	1.7	1.5	41.6
1934	1.5	1.2	1.1	1.1	6.8	6.2	5.8	2.8	1.2	1.4	1.1	[2] 1.2	31.4
1935	1.2	.8	.9	.6	1.6	9.1	7.5	6.5	1.8	2.0	2.0	1.7	35.7

[1] Partial record.
[2] Estimated.
[3] Partially estimated.

Records from January 1910 to December 1918 and October 1933 to September 1934 from reports of U. S. Geological Survey.
Records from May to December 1909 and from January 1919 to September 1933 from biennial reports of the Colorado State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 151.—*Run-off of San Luis Creek near Villa Grove, Colo.*

[Drainage area 255 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1922				0.9	1.2	0.6	0.3	0.4	0.3	0.4			
1923				1.2	.7	2.0	.6	2.0	2.0	[illegible]	1.4	[1] 0.7	
1924				9.3	13.1	5.0	.7	.6	.5	.5	.6		
1925				.9	.9	.5	.3	.6	[illegible]	[illegible]	.3		
1926				1.6	3.6	3.1	.8	.7	.4				

[1] Partially estimated.

Records from biennial reports of the Colorado State engineer.

TABLE 152.—*Run-off of Kerber Creek near Villa Grove, Colo.*

[Drainage area 39.5 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1922				[illegible]	[illegible]	[illegible]	0	[illegible]	0				
1923						[illegible]	1.1	2.0	1.0	0.7	[1] 0.5		
1924				[illegible]	[illegible]	[illegible]	1.0	.4	.3				
1925				1.1	2.0	.9	.5	.4	.3	[2] .3			
1926				1.5	4.3	3.4	1.0	.3	.2				

[1] Partially estimated. [2] Estimated.

Records from biennial reports of the Colorado State engineer.

TABLE 153.—*Run-off of Saguache Creek near Saguache, Colo.*

[illegible]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
[illegible]									2.6	2.6			
[illegible]			[illegible]	4.1	[illegible]	12.9	[illegible]	[illegible]	3.8	6.6	2.9		
[illegible]				[illegible]		14.0	8.2						
[illegible]						16.5	10.9	6.8	[illegible]	3.1	1.9	1.0	
[illegible]		1.5		[illegible]	13.6	14.0	5.7	3.7	3.0	[illegible]	[illegible]	2.0	[illegible]
[illegible]	1.6	2.1	3.1	3.4	11.3	11.5	6.6	9.9	4.2	[illegible]	2.8		
[illegible]			2.2	4.6	11.5	20.5	11.1	[illegible]	[illegible]	[illegible]	2.2	[illegible]	
[illegible]	1.6	1.7	2.5	2.8	[illegible]	9.2	6.0	4.5	[illegible]	[illegible]	2.7		
[illegible]				6.4	22.2	15.6	11.3	6.2	3.3	[illegible]	[illegible]		
[illegible]			3.6	3.4	17.3	19.8	7.1	4.6	[illegible]	[illegible]	3.0		
[illegible]			[1]	3.1	[illegible]	26.4	10.1	7.4	4.6	[illegible]	2.9		
[illegible]				3.4	11.2	13.2	7.0	5.0	[illegible]	[illegible]	2.1	[illegible]	
[illegible]	[illegible]	[3] 1.1	[illegible]	3.5	9.4	12.5	8.7	10.0	6.8	[illegible]	[illegible]		
[illegible]				15.3	26.9	16.7	6.8	3.3	2.3	[illegible]	[3] 1.9		
[illegible]				5.6	8.1	[illegible]	6.5	6.1	4.5	4.1	[3] 2.3	[3] 1.8	
[illegible]	[3] 1.5	[illegible]	[3] 1.8	7.7	14.8	13.6	6.2	3.7	2.3	3.7			
[illegible]				5.2	8.7	[illegible]	7.0	7.6	7.1	6.0	[illegible]		
[illegible]				6.7	21.4	17.5	6.1	4.2	[illegible]	[illegible]	2.7		
[illegible]				[illegible]	10.5	11.3	6.6	12.2	11.5	[illegible]	[3] 3.6		
[illegible]				[1]	[illegible]	[illegible]	4.4	7.9	3.3	2.9	-----		
[illegible]				[3] 3.3	[illegible]	[illegible]	2.4	1.9	1.8	1.9	[3] 1.5		
[illegible]				[3] 3.0	16.3	[illegible]	7.3	5.2	2.9	[illegible]	[3] 2.5		
1933				2.2	5.0	8.3	4.4	4.6	2.1	[illegible]	[1]		
[illegible]			...	3.1	3.8	1.7	1.4	2.2	1.9	1.4	1.4		
[illegible]			1.7	[illegible]	[illegible]	13.2	7.3	4.8	2.6	2.5			

[illegible]

Records from October 1934 to October 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 154.—*Run-off of Carnero Creek near La Garita, Colo.*

[Drainage area, 117 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
[illegible]				[illegible]	[illegible]	[illegible]	1.9	[illegible]	0.6	[illegible]			
[illegible]			1.0	[illegible]	[illegible]	2.8	.8	.8	.4	.4			
[illegible]				[illegible]	[illegible]	4.5	1.9	1.8	1.1	.6			
[illegible]					[illegible]	1.4	.5	2.1	.7	[illegible]			
[illegible]				1.5	2.8	1.1	.8	2.3	2.0	1.8			
[illegible]				7.9	10.6	3.5	1.2	.5	.2	.3	[illegible]		
1925			1.0	.9	1.0	.5	.9	1.3	.8	[illegible]	.5	[3] 0.3	
[illegible]	[3] 0.2	[illegible]	[3] .6	2.0	[illegible]	1.9	1.2	.7	.2	.4	[3] .2		
[illegible]			.7	.7	.7	.4	.5	.6	.6	[illegible]			
[illegible]				2.3	[illegible]	[illegible]	.6	.6	.5	.4			
[illegible]					1.2		.6	5.1	1.7	.9			
[illegible]				.8	.6	.4	.8	2.8	[illegible]	.5			
[illegible]					.9	.5	.4		.1	.2			
[illegible]				[illegible]	1.6	.8	.7	.4	.1	.1			
[illegible]				.4	.6	.6	.5	.7	[illegible]	.4			
1934				.6	[illegible]	.2	.1	.2	[illegible]	.2			
[illegible]				.7	[illegible]	2.2	1.3	.7	.3	.3			

[illegible]

[3] Partially estimated.

TABLE 155.—*Run-off of La Garita Creek near La Garita, Colo.*

[Drainage area, 61 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1919				[illegible]	[illegible]	[illegible]	[illegible]	2.2	[illegible]	[illegible]			
[illegible]			0.4	[illegible]	[illegible]	[illegible]	1.1	[illegible]	.6	.3			
[illegible]				[illegible]	3.2	7.5	4.0	2.8	1.7	.5			
[illegible]				.9	4.3	1.9		1.3	.6				
[illegible]					[illegible]	[illegible]	[illegible]	2.9	[illegible]	2.6			
[illegible]				7.5	[illegible]	[illegible]	1.1	.5	.3	.4	[illegible]		
[illegible]				1.1	[illegible]	.7	1.8	2.8	1.2	.8	.5	[illegible]	
[illegible]	[3] 0.3	[3] 0.3	[3] .4	2.3	7.2	[illegible]	1.2	.7	.2	[illegible]	[3] .4		
[illegible]				.9	[illegible]	.7	.7	.7					
1928					2.6	1.5	.9	.9	.6	.5	[illegible]		
[illegible]					2.4	1.4	.8		1.5				
[illegible]				[illegible]	.9	.7	1.0	2.5	.8	.6			
[illegible]					1.0	[illegible]	.4	.3	.2	.3			
[illegible]					[illegible]	1.2	.9	.6	.3	[1] .7			
[illegible]				[illegible]	.9	1.1		.7		.3			
[illegible]						.3	[illegible]		[illegible]				
[illegible]				.7	[illegible]	[illegible]	[illegible]		[illegible]		[illegible]		

[illegible]

Records from October 1934 to November 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 156.—*Run-off of Rio Grande below Taos Junction Bridge near Taos, N. Mex.*

[Drainage area, [illegible] square miles.[1] Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1925							[illegible]	[illegible]	43.3	48.3	50.8	39.7	
1926	31.4	31.8	[illegible]	[illegible]	175.0	168.0	[illegible]	17.7	15.9	16.9	27.8	32.8	668.3
1927	[3]33.0	[3]37.1	[3]45.3	51.4	[3]142.0	[3]150.0	[3]156.0	26.9	121.0	[4]107.0	[illegible]	[3]42.7	980.6
1928	[illegible]	37.9	47.4	32.8	[3]126.0	[3]83.7	14.9	[3]13.0	[3]12.0	14.0	21.3	21.5	470.0
1929	26.0	27.3	39.7	42.5	[3]141.0	[3]115.0	[3]23.6	[3]94.5	[3]85.8	63.6	[3]50.1	39.4	748.5
1930	30.1	[3]39.8	39.6	[3]64.0	53.3	[3]49.7	[3]27.6	[illegible]	[3]19.3	24.5	24.6	30.2	443.9
1931	[illegible]	28.8	44.4	30.0	27.1	17.0	13.8	11.2	20.1	23.0	19.1	30.3	288.6
1932	30.8	34.9	50.4	66.8	222.0	205.0	107.0	22.4	24.8	21.8	31.6	30.3	847.8
1933	29.1	24.0	36.9	22.5	[3]45.6	104.0	[3]25.9	[3]15.5	16.8	19.1	23.4	[illegible]	393.3
1934	30.5	35.0	30.2	20.8	23.0	14.3	12.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	244.9
1935	25.1	20.8	19.5	15.7	82.1	210.0	70.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[1] Exclusive of closed basin area, San Luis Valley, Colo.
[2] Partial record.
[3] Partially estimated.
[4] Estimated.

Records from July 1925 to September 1930 from reports of New Mexico State engineer.
Records from October 1930 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 157.—*Run-off of Rio Grande at Embudo, N. Mex.*

[Drainage area, 7,327 square miles.[1] Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in percent of mean
1890	26.9	30.7	[illegible]	124.0	305.0	244.0	98.0	50.1	32.4	34.6	36.6	40.0	1,064.2	123.7
1891	36.0	34.2	56.4	141.0	367.0	300.0	145.0	57.4	27.9	103.0	46.3	34.0	1,348.2	156.7
1892	30.6	34.3	[illegible]	177.0	301.0	187.0	33.1	11.7	9.0	[illegible]	18.9	19.9	899.5	[illegible]
1893	20.4	23.0	30.8	85.4	192.0	151.0	13.9	14.1	17.1	22.3	19.6	19.7	609.3	[illegible]
1894	19.6	18.3	[2]37.0	[2]90.0	[2]167.0	[2]50.0	[2]14.0	[2]16.0	[2]19.0	41.8	17.8	20.8	511.3	59.4
1895	29.2	27.9	46.5	151.0	165.0	180.0	82.1	66.4	37.8	30.4	36.4	32.8	885.5	103.0
1896	32.7	31.7	58.8	107.0	98.3	21.8	18.4	15.3	13.6	21.5	23.5	25.5	468.1	[illegible]
1897	24.2	22.7	34.5	101.0	335.0	275.0	78.3	20.8	20.5	94.6	67.7	33.9	1,108.2	128.8
1898	30.0	26.2	42.7	133.0	132.0	207.0	158.0	29.4	20.1	17.4	21.2	20.8	837.8	97.4
1899	28.9	26.7	46.8	64.9	58.8	14.8	18.3	14.5	18.4	21.9	31.8	29.4	375.2	43.6
1900	27.9	26.4	38.6	27.8	148.0	145.0	17.3	10.6	14.8	15.5	19.3	21.8	513.0	59.6
1901	21.1	25.9	31.9	38.8	192.0	102.0	21.8	27.7	21.4	20.4	21.2	26.1	553.3	64.3
1902	26.4	25.7	32.7	39.4	49.1	26.2	9.7	15.2	13.6	14.2	13.7	16.2	282.1	32.8
1903	19.5	20.8	48.4	58.7	158.0	534.0	92.6	20.5	20.7	19.9	25.8	17.4	1,036.3	120.5
1904	[3]20.0	[3]21.0	[3]16.0	[3]22.0	[3]16.0	[3]15.0	[4]8.0	[illegible]	[4]61.0	[3]122.0	[3]31.0	[3]30.0	406.0	47.2
1905	[3]33.0	[3]31.0	[3]78.0	[3]78.0	[3]515.0	[4]511.0	[3]34.0	[3]28.0	[3]17.0	[3]21.0	[3]28.0	[3]27.0	1,401.0	162.9
1906	30.0	29.0	34.0	76.0	307.0	360.0	131.0	53.0	41.0	77.0	56.0	43.0	1,237.0	143.8
1907 [3]	40.0	40.0	68.0	180.0	302.0	562.0	425.0	144.0	89.0	[illegible]	40.0	34.0	1,977.0	229.9
1908	[6]21.0	[6]21.0	[illegible]	[3]64.0	[3]80.0	[3]68.0	[3]37.0	[3]62.0	[3]34.0	[3]34.0	[3]29.0	[4]26.0	536.0	62.3
1909	[3]31.0	[3]32.0	[3]45.0	[3]103.0	[3]320.0	[3]371.0	[3]61.0	[3]50.0	[3]156.0	[3]73.0	[3]31.0	[4]39.0	1,312.0	152.5
1910	[3]35.0	[3]31.0	[3]103.0	[3]186.0	[3]310.0	[3]95.0	[illegible]	[3]20.0	[3]15.0	[3]22.0	[4]28.0	[4]30.0	[illegible]	103.0
1911	[3]34.0	[3]33.0	[illegible]	[3]50.0	[3]199.0	295.0	[3]303.0	[3]58.0	[3]57.0	[3]228.0	[illegible]	[4]43.0	1,391.0	162.1
1912	[3]40.0	[illegible]	[3]53.0	[3]83.0	[3]390.0	422.0	[3]77.0	[3]36.0	[7]22.0	29.8	[illegible]	27.1	1,252.5	145.7
1913	23.8	25.0	[illegible]	80.3	87.3	78.0	17.8	17.0	18.3	41.1	41.6	25.7	499.5	58.1
1914	29.1	30.7	[illegible]	76.2	196.0	228.0	92.8	[illegible]	68.4	67.0	41.1	30.6	980.0	113.9
1915	28.4	31.0	48.2	116.0	239.0	256.0	75.7	50.8	29.3	31.2	32.2	32.7	970.5	112.8
1916	[illegible]	39.5	70.8	98.4	310.0	198.0	65.2	117.0	44.0	74.4	79.4	45.0	1,176.1	136.7
1917	37.6	33.9	46.4	73.4	153.0	298.0	190.0	34.0	23.1	25.7	35.6	35.1	985.8	114.6
1918	27.5	27.9	45.1	32.9	74.2	90.2	42.8	14.8	37.8	26.8	32.1	35.7	487.8	56.7
1919	34.3	31.4	55.9	149.0	297.0	128.0	75.6	45.7	20.5	36.5	44.8	43.8	962.5	111.9
1920	32.6	41.9	47.2	62.2	455.0	570.0	174.0	36.9	32.6	37.0	46.6	35.4	1,578.4	183.5
1921	38.9	36.1	65.9	43.0	140.0	493.0	127.0	100.0	[illegible]	34.2	43.0	41.8	1,211.1	140.8
1922	37.6	36.2	53.4	50.1	242.0	325.0	68.6	16.9	16.5	18.1	28.4	31.1	923.9	107.4
1923	32.7	28.7	32.8	39.7	179.0	198.0	42.5	60.3	76.0	108.0	72.5	41.8	912.0	106.0
1924	34.4	42.7	59.2	213.0	404.0	147.0	37.4	24.1	22.6	23.6	28.6	39.8	1,076.4	125.2
1925	[7]29.2	31.7	56.4	56.3	[illegible]	29.6	22.0	33.0	40.7	46.3	46.2	48.8	489.2	56.9
1926	45.9	42.6	70.6	96.3	241.0	230.0	[7]40.3	19.5	16.3	18.5	29.8	[7]36.6	887.4	103.2
1927	[illegible]	[7]34.3	46.9	52.8	162.0	148.0	[7]174.0	33.5	134.0	104.0	52.4	[7]40.4	1,017.1	118.3
1928	[7]41.1	37.2	50.1	42.7	159.0	102.0	15.8	17.4	15.5	16.6	[illegible]	25.3	550.9	64.1
1929	[7]25.3	26.4	40.3	49.8	162.0	124.0	[7]28.7	101.0	96.0	75.9	[illegible]	44.5	828.3	96.3
1930	35.6	[7]42.0	41.6	75.3	61.5	56.8	31.8	42.9	21.9	26.0	29.3	30.5	495.2	57.6
1931	28.7	32.5	51.0	37.9	36.4	25.9	16.2	14.3	25.0	26.5	22.9	33.4	360.7	41.9
1932	29.9	34.3	54.9	77.8	253.0	210.0	109.0	25.0	24.3	23.2	32.4	33.0	906.8	105.4
1933	29.5	26.0	41.8	22.9	51.8	118.0	27.8	16.7	19.7	20.6	23.4	32.0	430.2	50.0
1934	33.0	39.0	31.8	22.8	23.4	14.8	12.8	13.6	15.0	15.7	[illegible]	23.1	260.4	30.3
1935	27.3	23.0	20.4	22.9	111.0	249.0	71.1	34.0	30.5	29.2	30.0	34.6	[illegible]	79.4
Mean	30.6	31.0	48.3	82.0	200.1	205.7	72.8	39.2	36.0	46.9	35.3	32.2	860.1	
Percent of annual	3.56	3.60	5.62	9.53	23.27	23.92	8.46	4.56	4.19	5.45	4.10	3.74	100.0	

[1] Exclusive of closed basin area, San Luis Valley, Colo.
[2] Estimated by reference to Rio Grande near Del Norte from monthly relation curves.
[3] Estimated by reference to Rio Grande near Lobatos from monthly relation curves.
[4] Mean of estimates by reference to Rio Grande near Lobatos and to Rio Grande at Otowi Bridge from monthly relation curves.
[5] Mean of measured run-off of Rio Grande near Lobatos and at Otowi Bridge.
[6] Estimate based upon relation of missing months to remaining months of the year as indicated by monthly means for all complete years.
[7] Partial record extended.

Records as published by U. S. Geological Survey: Previous to October 1913 from Water Supply Paper No. 358, except as noted; October 1930 to September 1934
Records from October 1913 to September 1930 from reports of New Mexico State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 158.—*Run-off of Rio Grande at Otowi Bridge, N. Mex.*

[illegible]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in percent of mean
[illegible]	[illegible]	40.0	[illegible]	298.0	600.0	325.0	120.0	77.0	46.0	47.0	[illegible]	[illegible]	1,739.0	128.3
[illegible]	46.0	47.0	97.0	340.0	720.0	400.0	170.0	89.0	39.0	145.0	[illegible]	[illegible]	2,196.0	162.0
[illegible]	37.0	47.0	120.0	420.0	592.0	254.0	48.0	14.0	8.0	15.0	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	18.0	26.0	28.0	200.0	380.0	208.0	27.0	18.0	21.0	29.0	[illegible]	[illegible]	[illegible]	71.0
[illegible]	[2] 17.0	[2] 17.0	[2] 50.0	[2] 135.0	[2] 240.0	[2] 43.0	[2] 17.0	22.0	[2] 20.0	[illegible]	[illegible]	[2] 40.0	[illegible]	48.5
[illegible]	[2] 34.0	32.8	84.3	338.0	284.0	276.0	109.0	91.1	43.0	42.1	[illegible]	43.8	[illegible]	105.3
[illegible]	36.9	[illegible]	81.2	207.0	166.0	31.8	25.3	14.9	17.8	28.3	[illegible]	30.0	[illegible]	51.9
[illegible]	28.7	30.1	[illegible]	303.0	702.0	366.0	97.3	27.4	40.5	136.0	[illegible]	[illegible]	1,895.9	140.1
[illegible]	21.7	21.9	[illegible]	266.0	200.0	224.0	162.0	39.2	19.3	21.9	[illegible]	39.2	1,087.2	[illegible]
[illegible]	26.0	35.6	81.2	176.0	118.0	23.7	36.6	[illegible]	53.1	26.6	[illegible]	38.2	682.2	50.5
[illegible]	36.8	32.3	52.8	51.5	212.0	173.0	18.3	10.1	[illegible]	23.8	25.3	29.0	707.5	52.3
[illegible]	24.4	36.5	45.6	83.4	319.0	131.0	44.8	50.8	31.5	30.2	27.5	28.5	[illegible]	63.4
[illegible]	29.6	27.2	33.7	97.6	73.6	28.2	16.7	34.2	28.8	17.2	18.4	19.2	421.4	31.4
[illegible]	23.1	24.7	75.2	172.0	107.0	709.0	137.0	26.6	22.3	21.8	25.2	23.6	1,667.5	123.2
[illegible]	20.9	21.2	21.3	27.3	24.2	17.0	15.1	92.0	148.0	253.0	49.4	35.4	[illegible]	53.8
1905	43.5	[illegible]	158.0	219.0	785.0	573.0	53.7	38.7	23.2	26.0	38.0	37.9	2,047.6	151.1
[illegible]	[4] 36.0	[4] 35.0	[illegible]	[4] 175.0	[5] 655.0	[4] 445.0	[4] 155.0	[4] 83.0	[4] 54.0	[4] 101.0	[4] 78.0	[4] 54.0	1,917.0	141.6
[illegible]	[4] 57.0	[illegible]	[illegible]	[4] 385.0	[5] 188.0	[4] 670.0	[4] 485.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	203.0
[illegible]	[illegible]	[5] 48.0	[illegible]	[4] 150.0	[illegible]	[4] 152.0	[4] 60.0	[illegible]	[illegible]	[illegible]	[illegible]	[4] 31	[illegible]	75.6
[illegible]	[4] 39.0	[4] 40.0	[4] 61.0	[4] 235.0	[5] 570.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	29.1	[illegible]	[illegible]	143.0
[illegible]	37.4	[illegible]	200.0	305.0	426.0	130.0	11.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	93.9
1911	47.7	[illegible]	91.6	150.0	108.0	310.0	350.0	[illegible]	[illegible]	[illegible]	[illegible]	77.5	[illegible]	156.0
[illegible]	48.6	[illegible]	94.7	139.0	701.0	[illegible]	[6] 117.0	53.0	38.3	38.2	[illegible]	32.5	1,909.4	141.0
1913	33.8	[illegible]	48.9	146.0	180.0	112.0	[illegible]	16.8	25.8	49.9	[illegible]	[illegible]	771.4	57.0
1914	[illegible]	42.8	90.4	170.0	373.0	259.0	140.0	117.0	83.3	87.3	[illegible]	36.4	1,496.1	110.4
1915	[7] 37.0	[7] 40.0	[7] 73.0	[7] 234.0	[7] 460.0	[7] 483.0	91.5	71.2	43.4	39.9	[illegible]	38.7	1,647.2	121.7
[illegible]	44.1	49.6	194.0	266.0	551.0	325.0	98.5	132.0	50.7	[6] 165.0	[illegible]	55.6	2,026.3	151.1
[illegible]	42.1	41.5	64.8	163.0	312.0	455.0	196.0	37.6	27.8	24.8	[illegible]	35.2	1,437.2	106.2
[illegible]	32.7	32.6	67.8	71.4	[illegible]	136.0	65.5	26.4	[6] 41.0	[6] 31.0	[6] 40.0	44.5	773.9	57.3
[illegible]	[illegible]	33.6	86.2	315.0	[illegible]	201.0	138.0	88.9	36.1	53.3	53.6	[illegible]	1,665.5	123.1
[illegible]	48.5	77.7	85.8	142.0	[illegible]	705.0	184.0	59.7	37.3	46.7	62.5	48.1	2,357.6	174.0
[illegible]	45.1	47.1	102.0	72.3	[illegible]	672.0	108.0	192.0	94.7	47.4	49.8	53.5	[illegible]	128.7
[illegible]	53.5	50.2	76.1	107.0	[illegible]	369.0	82.0	20.7	13.5	15.9	34.9	42.2	[illegible]	93.6
[illegible]	44.3	[illegible]	56.8	95.4	397.0	261.0	58.2	82.0	118.0	138.0	[illegible]	70.0	1,465.1	[illegible]
[illegible]	44.6	60.5	60.5	[illegible]	684.0	204.0	55.4	31.2	23.6	28.5	41.5	49.4	1,651.2	122.2
[illegible]	46.1	50.1	79.6	151.0	119.0	48.0	48.7	71.8	12.6	[illegible]	[illegible]	57.6	845.3	62.5
[illegible]	[illegible]	[illegible]	75.6	175.0	446.0	335.0	49.0	20.1	22.6	24.9	34.5	38.3	1,316.4	97.3
[illegible]	35.1	40.1	66.7	177.0	[illegible]	224.0	186.0	[illegible]	[illegible]	131.0	72.1	53.1	1,631.4	120.3
[illegible]	50.7	19.1	75.1	96.4	348.0	135.0	18.7	[illegible]	[illegible]	18.1	32.6	30.7	893.3	66.0
[illegible]	35.7	38.3	63.5	120.0	347.0	184.0	[illegible]	[illegible]	[illegible]	104.0	66.0	56.4	1,377.5	101.7
[illegible]	48.2	59.1	61.6	223.0	155.0	96.6	[illegible]	[illegible]	[illegible]	40.7	[illegible]	40.1	925.2	68.4
1931	36.6	46.1	[illegible]	71.3	124.0	38.5	21.6	[illegible]	[illegible]	63.0	[illegible]	46.5	[illegible]	46.3
[illegible]	39.2	62.6	130.0	327.0	537.0	296.0	113.0	[illegible]	31.3	35.1	[illegible]	40.6	[illegible]	127.7
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	177.0	[illegible]	[illegible]	[illegible]	31.3	30.2	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19.4	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mean	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	276.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
Percent of annual	2.80	3.03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

[1]–[6] [illegible]

[7] Estimated by reference to sum of Rio Grande at Embudo and Rio Chama near Chamita from monthly relation curves.

[illegible]
Records from October 1913 to September 1930 from reports of New Mexico State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 159.—*Run-off of Rio Grande at Cochiti, N. Mex.*

[Drainage area 11,661 square miles.[1] Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1925	[illegible]	59.5	93.7	158.0	135.0	46.1	43.3	54.4	48.8	70.2	61.3	54.7	[illegible]
[illegible]	[illegible]	[2] 71.0	[2] 118.0	[2] 242.0	[2] 532.0	[2] 220.0	[2] 62.8	[2] 18.5	[2] 18.0	21.0	30.1	39.9	1,435.3
1927	[illegible]	42.7	63.8	[illegible]	[illegible]	218.0	207.0	55.2	[2] 172.0	130.0	76.2	[2] 62.5	1,677.3
1928	[2] 53.5	52.5	76.0	[illegible]	[illegible]	[illegible]	15.0	[2] 29.1	14.3	[2] 14.3	[2] 39.9	[illegible]	854.4
[illegible]	[2] 40.1	37.2	[illegible]	113.0	[illegible]	[illegible]	[illegible]	157.0	133.0	108.0	[2] 83.0	[illegible]	1,366.1
1930	[2] 48.3	[illegible]	60.1	[illegible]	[illegible]	101.0	55.0	[illegible]	23.0	32.2	32.1	35.4	874.4
1931	36.6	[illegible]	57.8	[illegible]	126.0	40.0	[illegible]	20.7	[illegible]	50.9	[illegible]	47.7	593.0
[illegible]	42.2	80.0	121.0	303.0	488.0	256.0	167.0	36.0	30.2	[illegible]	46.3	[2] 42.8	1,645.3
[illegible]	[2] 43.9	[illegible]	63.2	[illegible]	[illegible]	168.0	[illegible]	31.8	26.5	22.6	25.2	[illegible]	706.3
1934	[illegible]	42.5	37.9	61.7	[illegible]	[illegible]	4.4	5.0	15.4	10.7	15.1	29.5	503.5
1935	33.7	30.8	[illegible]	[illegible]	[illegible]	[illegible]	73.5	[illegible]	[illegible]	[illegible]	51.1	[illegible]	1,021.8

[1]–[3] [illegible]

[illegible]

TABLE 160.—*Run-off of Rio Grande at San Felipe, N. Mex.*

[Drainage area, [illegible] square miles.[1] Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1926	64.6	[illegible]	125.0	247.0	549.0	236.0	66.2	22.3	21.5	24.9	53.9	[illegible]	1,535.6
1927	43.3	47.9	74.6	174.0	460.0	251.0	317.0	89.9	204.0	137.0	82.7	62.2	1,943.6
1928	[2] [illegible]	[illegible]	95.4	[2] 98.8	[2] 344.0	149.0	24.1	77.0	16.0	21.3	35.3	[2] 34.5	1,002.5
1929	[illegible]	[2] 36.9	56.1	107.0	340.0	161.0	[2] 77.2	[2] 169.0	180.0	111.0	84.8	74.5	1,432.6
1930	[illegible]	[illegible]	66.3	218.0	153.0	106.0	82.8	58.1	22.2	38.6	34.2	36.2	924.6
1931	[illegible]	47.1	60.5	66.0	139.0	36.8	21.4	23.4	61.2	42.2	35.4	[2] 49.3	620.7
1932	[2] 40.1	64.2	118.0	299.0	564.0	291.0	[2] 160.0	[2] 42.7	[2] 27.2	33.9	[2] 47.4	[2] 44.3	1,731.8
1933	[3] 44.3	[2] 42.7	[2] 78.8	[illegible]	[2] 166.0	216.0	51.7	[2] 31.9	[2] 28.5	27.1	39.4	[illegible]	848.2
1934	[illegible]	53.4	42.7	[2] 67.8	48.7	12.6	5.9	8.0	18.6	[illegible]	19.5	32.4	379.1
1935	32.8	30.7	29.3	58.1	209.0	385.0	93.1	120.0	[illegible]	43.5	[illegible]	44.1	1,187.4

[1] Exclusive of closed basin area, San Luis Valley, Colo.
[2] Partially estimated.
[3] [illegible]

Records from January 1926 to September 1930 from reports of the New Mexico State engineer.
Records from October 1930 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 161.—*Run-off of Rio Grande at San Marcial, N. Mex.*

[Drainage area, 24,176 square miles.[1] Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in percent of mean
1890 [2]	27.0	33.0	51.0	190.0	500.0	290.0	54.0	61.0	37.0	6.0	27.0	41.0	1,317.0	116.8
1891	40.0	66.0	152.0	328.0	1,000.0	430.0	126.0	56.0	92.0	135.0	32.0	31.0	2,488.0	220.6
1892 [2]	34.0	46.0	72.0	253.0	605.0	200.0	44.0	1.0	2.0	0	2.0	10.0	1,269.0	112.5
1893	[2] 23.0	[2] 24.0	[2] 17.0	[2] 100.0	[2] 330.0	[2] 25.0	[3] 0	[3] 0	[3] 0	[3] 4.0	[3] 0	[3] 18.0	541.0	48.0
1894	[3] 13.0	[3] 18.0	[3] 38.0	[3] 125.0	[4] 190.0	[4] 33.0	[4] 16.0	[4] 0	[4] 3.2	[3] 55.0	[3] 0	[3] 19.0	510.2	45.2
1895	[3] 33.0	53.8	129.0	279.0	223.0	233.0	149.0	179.0	[5] 25.0	[5] 23.0	[3] 26.0	[3] 38.0	1,390.8	123.4
1896	[6] 40.0	39.1	41.8	187.0	124.0	9.8	28.7	7.3	7.7	[illegible]	12.4	38.1	581.5	51.6
1897	19.5	24.3	40.8	213.0	755.0	366.0	66.0	6.1	114.0	282.0	176.0	153.0	2,215.7	196.5
1898	57.7	59.4	62.2	271.0	166.0	126.0	167.0	13.8	3.7	0	10.2	23.4	960.4	85.2
1899	27.9	24.6	[illegible]	54.1	35.0	1.0	28.4	6.4	2.9	.7	[illegible]	21.8	239.8	21.3
1900	40.6	35.1	33.2	5.3	124.0	160.0	.1	0	56.1	.1	2.4	10.1	467.0	41.4
1901	21.0	25.5	15.1	23.7	256.0	96.2	59.3	65.5	37.6	17.0	20.1	19.2	656.2	58.2
1902	22.7	17.4	8.0	40.1	26.8	6.4	0	49.2	13.3	.8	4.6	11.3	200.6	17.8
1903	17.2	21.9	46.8	100.0	318.0	660.0	77.8	3.1	1.4	.5	5.5	18.9	1,271.1	112.7
1904	16.8	18.9	6.1	0	0	0	10.5	56.0	44.7	463.0	51.8	41.8	709.6	62.9
1905	39.1	63.9	218.0	279.0	962.0	714.0	35.8	20.1	5.3	[illegible]	42.4	34.3	2,421.2	214.7
1906	36.5	39.7	56.9	163.0	501.0	345.0	118.0	43.2	25.5	70.8	77.8	86.1	1,563.5	138.6
1907	60.6	67.7	92.5	223.0	369.0	524.0	329.0	166.0	161.0	64.5	56.5	44.7	2,158.5	191.4
1908	43.6	48.0	77.4	124.0	165.0	90.5	49.0	95.7	9.7	2.8	29.9	38.4	774.0	68.6
1909	41.6	34.3	52.6	104.0	336.0	290.0	48.1	52.7	179.0	59.7	39.6	41.8	1,279.4	113.5
1910	61.3	42.0	144.0	190.0	309.0	63.1	1.1	7.3	3.0	.6	8.9	23.2	853.5	75.7
1911	30.2	35.7	87.1	92.5	304.0	270.0	392.0	63.2	39.2	313.0	116.0	57.0	1,799.9	159.6
1912	50.3	44.4	77.4	118.0	502.0	502.0	114.0	22.8	[illegible]	9.0	27.6	25.0	1,500.1	133.0
1913	23.4	38.1	35.3	99.1	129.0	95.1	6.9	.2	4.9	33.1	35.2	24.9	525.2	46.6
1914	38.1	40.1	65.9	116.0	267.0	212.0	160.0	86.2	33.1	[illegible]	43.2	40.0	1,179.1	104.6
1915	33.2	38.0	53.2	271.0	394.0	309.0	120.0	46.2	17.9	13.0	22.7	35.4	1,353.6	120.0
1916	47.8	47.1	164.0	234.0	488.0	206.0	45.7	97.8	19.4	162.0	88.1	48.9	1,648.8	146.2
1917	47.6	37.9	38.8	94.6	239.0	367.0	174.0	6.1	7.7	1.0	14.5	28.4	1,054.6	93.5
1918	28.0	22.8	45.6	30.5	117.0	67.2	22.4	1.7	0	11.0	24.3	40.7	411.2	36.5
1919	34.4	35.4	75.6	315.0	487.0	167.0	248.0	81.8	6.8	33.3	40.0	55.1	1,579.4	140.1
1920	51.3	87.4	84.2	139.0	676.0	863.0	176.0	[illegible]	5.9	14.7	46.1	39.9	[illegible]	197.1
1921	45.0	44.5	81.8	44.4	216.0	649.0	206.0	158.0	61.9	25.9	37.7	55.2	1,625.4	144.1
1922	58.5	48.8	56.9	81.5	344.0	311.0	49.6	0	0	0	0	12.7	963.0	85.4
1923	40.9	40.1	42.0	64.9	305.0	221.0	28.8	78.1	121.0	99.6	104.0	68.2	1,223.6	108.5
1924	56.0	77.1	76.9	407.0	608.0	134.0	50.0	7.2	2.9	0	3.8	15.1	1,438.0	127.5
1925	17.4	37.8	41.4	98.2	53.9	3.6	1.3	21.3	27.0	32.0	40.3	44.6	418.8	37.1
1926	45.2	37.1	59.0	118.0	440.0	272.0	27.2	1.6	3.9	3.2	8.9	31.4	1,047.5	92.9
1927	38.7	32.9	35.4	134.0	317.0	168.0	154.0	65.8	189.0	105.0	61.3	47.9	1,349.0	119.6
1928	[illegible]	47.0	49.7	40.2	251.0	106.0	.6	9.4	5.0	0	4.3	27.8	590.6	52.4
1929	26.5	29.6	43.0	78.8	276.0	132.0	38.1	275.0	308.0	123.0	76.2	58.4	1,464.6	129.9
1930	44.8	52.9	65.2	186.0	124.0	62.5	79.3	53.1	4.8	4.3	18.0	36.1	731.0	64.8
1931	39.2	45.8	49.6	53.1	92.8	5.1	8.0	6.9	59.0	55.6	26.8	47.9	489.8	43.4
1932	43.7	64.0	98.2	235.0	431.0	212.0	157.0	60.7	12.2	16.8	31.6	37.3	1,399.5	124.1
1933	45.1	38.6	47.5	16.8	94.5	253.0	55.2	37.9	42.3	15.9	23.0	46.2	716.0	63.5
1934	48.9	46.3	26.7	29.5	4.4	.2	0	31.7	25.5	.9	2.6	27.8	244.5	21.7
1935	44.9	39.1	23.4	21.5	182.0	368.0	36.0	108.0	64.6	37.2	51.2	53.6	[illegible]	91.3
Mean	37.9	41.6	63.4	138.5	318.2	230.8	81.7	48.9	41.2	[illegible]	34.4	38.4	1,127.7	
Percent of annual	3.36	[illegible]	[illegible]	12.28	28.22	20.47	7.24	[illegible]	[illegible]	[illegible]	3.05	3.41	100.0	

[1] Exclusive of closed basin area, San Luis Valley, Colo.
[2] Estimated by reference to Rio Grande at El Paso from monthly relation curves for period 1897–1913.
[3] Estimated by reference to Rio Grande at Embudo from monthly relation curves.
[4] Estimated by reference to Rio Grande near Del Norte from monthly relation curves for period [illegible].
[5] Estimated by reference to Rio Grande at Otowi Bridge from monthly relation curves.
[6] Partial record extended.

Records as published by U. S. Geological Survey: Previous to October 1913 from Water Supply Paper No. 358 except as noted; October 1913 to December 1930.
[illegible]

TABLE 162.—*Run-off of Costilla River near Costilla, N. Mex.*

[illegible]

Year	[illegible]	February	[illegible]	[illegible]	[illegible]	June	[illegible]	[illegible]	Septem-ber	[illegible]	Novem-ber	Decem-ber	[illegible]
[illegible]	[illegible]	[illegible]	2.3	[illegible]	[illegible]	[illegible]	4.9	3.2	2.0	5.2	2.1	[illegible]	38.2
[illegible]	[illegible]	[illegible]	1.9	4.8	20.2	20.7	7.6	3.2	2.2	[illegible]	[2] 2.0	[1] 1.0	[illegible]
[illegible]	1.0	[1] 1.0	[1] 1.8	6.0	6.5	4.4	1.8	1.6	.9	[illegible]	1.3	1.1	28.5
[illegible]	1.3	1.2	2.7	[illegible]	13.7	7.8	7.3	6.1	[1] 1.6	[illegible]	[1] 1.0	[1] 1.0	49.2
[illegible]	1.2	1.1	1.7	7.7	17.7	21.6	[illegible]	[illegible]	1.6	[illegible]	1.5	[1] 1.3	69.9
[illegible]	1.2	1.1	2.0	5.6	14.8	9.0	4.8	[illegible]	1.5	[illegible]	[1] 1.2	1.2	[illegible]
[illegible]	[illegible]	.9	[illegible]	[illegible]	13.1	17.1	[illegible]	3.5	1.7	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	1.1	1.7	[illegible]	16.4	14.4	[illegible]	3.5	1.6	[1] 1.7	[1] 1.2	[1] 1.1	51.3

[illegible]

[illegible]

TABLE 163.—[illegible]

[illegible]

Year	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Novem-ber	[illegible]	[illegible]
1912										[illegible]	1.5	1.2	
[illegible]	[2] 1.2	[illegible]	[2] 1.4	2.7	6.3	6.1	3.1	1.8	1.6	[illegible]	1.4	[illegible]	[illegible]
[illegible]													
[illegible]	[illegible]	1.2	1.3	3.7	13.0	[illegible]	7.9	[illegible]	2.6	2.0	1.6	[1] 1.3	55.9
[illegible]	1.9	1.6	2.4	4.8	25.8	20.2	6.8	5.0	2.7	2.5	2.0	1.2	76.9
[illegible]	1.7	1.2	[illegible]	1.8	8.3	17.5	[illegible]	2.6	1.7	1.3	.9	.8	47.1
[illegible]	[illegible]	1.3	1.2	2.2	10.2	11.7	5.8	2.6	2.0	1.5	1.0	.5	41.2
[illegible]	.6	1.1	.6	2.4	13.7	12.6	12.3	[illegible]	2.1	1.7	1.3	1.8	[illegible]
[illegible]	1.7	1.4	1.7	3.4	19.0	5.8	3.6	3.7	1.8	1.7	1.5	1.4	46.7
1921	[illegible]	1.5	2.2	2.8	42.7	29.2	8.7	[illegible]	4.0	2.1	1.6	1.8	104.5
1922	1.9	1.7	2.7	2.9	8.0	5.4	3.0	[illegible]	1.3	1.3	1.2	1.2	32.9
[illegible]	[illegible]	1.7	[illegible]	2.8	[illegible]	[illegible]	5.0	3.2	3.2	3.2	2.1	2.5	49.7
[illegible]	2.7	[illegible]	4.4	11.2	21.7	19.6	18.2	1.9	1.8	1.9	1.7	1.5	88.6
[illegible]	1.2	[illegible]	1.8	3.0	5.1	3.3	2.5	[illegible]	2.1	2.0	[illegible]	[illegible]	27.8
[illegible]	[illegible]	[3] 1.4	[illegible]					[illegible]	[3] 2.0	[3] 1.8	[3] 1.4	[3] 1.6	
[illegible]	1.1	.6	[illegible]	3.9	10.3	9.2	4.2	2.5	2.6	[3] 2.6	[3] 1.3	1.1	41.0
[illegible]	[3] 1.4	[3] 1.3	[3] 1.3	[3] 2.0	9.3	7.8	[3] 4.0	[3] 2.5	1.9	1.3	1.3	1.1	35.2
[illegible]	1.2	1.0	1.2	2.5	[3] 8.6	[3] 9.5	[3] 4.3	5.1	4.5	2.6	1.8	[3] 1.4	43.7
[illegible]	1.3	1.1	[illegible]	5.9	7.0	6.5	4.7	7.4	3.1	2.3	1.5	1.5	43.6
[illegible]	1.4	1.2	[illegible]	2.1	6.0	5.3	2.5	1.3	2.5	3.1	1.4	1.1	29.1
[illegible]	[3] 1.5	1.4	[illegible]	8.5	18.5	[3] 12.0	5.7	3.0	2.0	[3] 1.8	1.3	1.1	58.6
[illegible]	1.3	[3] 1.1	[illegible]	[illegible]	4.0	8.2	4.2	1.9	1.5	1.4	1.1	1.0	28.4
[illegible]	[illegible]	[illegible]	[illegible]	2.1	[illegible]	[illegible]	1.8	[3] 1.6	[3] 1.7	1.3	.9	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[3] 2.2	[illegible]	19.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	45.4

[illegible]

TABLE 164.—*Run-off of Rio Colorado below Questa, N. Mex.*

[Drainage area 167 square miles. Unit, 1,000 acre-feet.]

Year	[illegible]	[illegible]	March	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	2.8	[illegible]	2.4	3.5		(1)	[illegible]	2.6	[illegible]	[illegible]	[illegible]	1.5	
1913	1.6	1.3	1.5	[illegible]	7.2	[illegible]	2.6	1.5	1.3	1.7	[illegible]	1.1	30.7
[illegible]	1.3	1.1	1.1	5.9	19.1	[illegible]	5.0	4.4	3.0	[illegible]	1.8	1.2	[illegible]
[illegible]	[illegible]	1.5	1.7	4.8	17.0	25.4	10.3	4.4	3.0	[illegible]	2.1	[illegible]	76.2
[illegible]	1.9	2.1	3.3	[illegible]	18.0	19.3	[illegible]	[illegible]	3.2	3.7	2.8	2.2	[illegible]
[illegible]	2.6	1.9	1.8	3.2	12.1	18.1	[illegible]	3.3	2.5	1.9	1.7	1.3	58.4
[illegible]	1.3	[illegible]	1.8	[illegible]	10.5	11.1	7.4	2.8	[illegible]	[illegible]	1.9	1.9	47.3
[illegible]	2.0	1.8	2.0	4.0	16.7	12.7	[illegible]	3.8	2.7	2.6	[illegible]	1.9	62.9
[illegible]	2.0	1.8	[illegible]	3.3	21.5	32.3	11.7	[illegible]	4.5	3.1	[illegible]	1.5	[illegible]
1921	1.4	[illegible]	2.2	3.1	20.5	[illegible]	8.7	7.1	3.7	3.0	[illegible]	[illegible]	[illegible]
1922	1.9	1.9	[illegible]	3.1	8.7	[illegible]	1.4	[illegible]	1.4	1.5	1.4	1.3	33.0
[illegible]	1.4	1.1	1.4	1.8	12.7	9.2	5.3	3.6	[illegible]	2.1	1.7	1.0	[illegible]
[illegible]	[illegible]	.7	1.8	[illegible]	[illegible]	21.2	12.8	3.6	2.3	2.1	[illegible]	1.9	73.0
[illegible]	1.3	1.4	2.3	5.2	7.7	5.4	[illegible]	[illegible]	1.8	1.7	1.6	1.6	33.9
[illegible]	.9	1.3	1.7	7.2	9.3			.3	3.8	[illegible]	[illegible]	1.1	....
[illegible]	1.1	1.7	[illegible]	[illegible]	[illegible]	[illegible]	7.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	61.7
[illegible]	[illegible] 2.0	[3] 1.2	[illegible]	3.4	[illegible]	19.9	4.5	4.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

TABLE 165.—*Run-off of Rio Hondo at Valdez, N. Mex.*

[Drainage area, [illegible] square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1915												(1)	
1916	0.8	0.9	1.4	2.7	10.8	12.[illegible]				(1)	[illegible]	0.9	
1917	1.0	.8	.8	1.0	3.3	(1)	3.8	0.8	0.7	0.2			
1918	[illegible]	[illegible]	.8	[illegible]	3.2	5.2	2.7	.6		.2	[illegible]	[illegible]	16.7
1919	[illegible]	[illegible]	[illegible]	1.6	[illegible]	4.6	2.4	.7		.6	[illegible]	[illegible]	18.2
1920	1.2	1.1	.7	1.4	7.[illegible]	7.4	2.3	.7	.6	.4	[illegible]	[illegible]	25.0
1921		.6	.7	1.0	[illegible]	9.7	2.4	3.9	1.9	.8			28.9
1922	[illegible]	.6	[illegible]	1.0	[illegible]	2.0	.3	.3	.2				[illegible]
1923	[illegible]			1.1	[illegible]	5.0	.5	.6	.7	1.2	[illegible]	[illegible]	18.7
1924	[illegible]	[illegible]		2.5	[illegible]	8.3	3.1	1.2	1.1	1.1	[illegible]	[illegible]	[illegible]
1925	[illegible]	.9	.9	2.2	[illegible]	.7	.3	.4	.2	.2	[illegible]	[illegible]	[illegible]
1926	[illegible]	².6	².6	2.0	9.0	10.9	³1.9	².6	.7	.5		[illegible]	[illegible]
1927	[illegible]	.7	1.3	3.4	[illegible]	6.3	1.2	.5	1.4	1.4	[illegible]	[illegible]	[illegible]
1928	[illegible]	³.8	.8	1.0	[illegible]	3.4	.3	.4	.2	.1	.4	².7	15.5
1929	[illegible]	².6	.7	1.4	4.7	5.2	[illegible]	1.4	2.4	2.1	1.1	².8	21.6
1930	.7	[illegible]	[illegible]	3.1	2.4	3.2	1.6	2.6	.5	.5	[illegible]	.9	17.6
1931	[illegible]	[illegible]	.5	.7	[illegible]	.9	.2	.3	1.4	2.1	[illegible]	[illegible]	10.4
1932	1.1	[illegible]	1.4	4.5	9.7	6.4	1.7	.8	.5	.2	.4	.6	28.2
1933	[illegible]	[illegible]	.6	.5	[illegible]	5.1	1.0	.5	.3	0	.1	.8	11.7
1934	[illegible]	[illegible]		[illegible]	1.8	.4	.2	.2	.3				

¹ Partial record.
² Estimated.
³ Partially estimated.

Records from December 1915 to September 1930 from reports of New Mexico State engineer.
Records from October 1930 to September 1934 from reports of U. S. Geological Survey.

TABLE 166.—*Run-off of Rio Hondo at Arroyo Hondo, N. Mex.*

[Drainage area, 71 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1912							2.3	1.8	1.6	0.5	0.8	1.6	
1913	0.7	0.7	0.8	1.2	2.8	2.6	1.4	.5	.5	.6	.8	.7	13.3
1914	.8	[illegible]	1.0	1.1	3.9	3.1	1.6	.8	.5	.7	.8	.8	15.9
1915	¹1.0	.9	1.0	2.5	10.7	15.5	3.9	.8	.6	.6	.7	¹1.3	[illegible]
1916	1.6	1.6	2.5	4.8	15.0	13.0	2.8	1.7	1.6	1.7	1.6	1.7	49.6
1917	1.5	1.3	1.3	1.4	4.9	9.5	2.8	.0	.2	.6	.5	1.1	25.1
1918	.8	.9	1.1	1.5	4.1	4.4	1.3	.5	.7	.7	.6	.8	17.4
1919	1.1	.7	1.0	2.3	7.0	6.4	3.5	.8	.5	1.3	1.5	1.6	27.7
1920	1.9	1.4	.8	1.3	11.4	15.1	3.2	1.0	.8	.5	.7	1.1	39.2
1921	.9	.9	.8	.9	7.1	10.4	4.1	3.8	2.0	.8	1.1	[illegible]	34.1
1922	1.3	1.0	1.0	1.3	3.0	1.8	.3	.4	.3	.4	.4	.5	11.7
1923	.6	.7	.9	1.8	7.2	5.3	1.3	1.5	2.0	2.3	2.0	[illegible]	27.1
1924	1.0	.9	1.3	2.9	10.3	7.0	2.7	.6	.9	.8	.8	.8	30.0
1925	.7	.5	1.1	1.9	1.2	.4	.4	.3	.3	.9	1.0	1.1	9.8
1926	²1.0	¹.9	¹1.0	²2.1	5.7	²6.3	1.7	².5	².6	.5	.7	.8	[illegible]
1927	.9	.7	1.0	2.6	7.5	6.6	1.1	.7	[illegible]	1.4	[illegible]	1.1	26.4
1928	1.1	1.5	1.0	1.0	4.5	2.9	.6	.4	.2	[illegible]	.4	1.2	15.0
1932	(³)	1.5	1.9	5.0	10.7	6.0	1.4	.8	1.1	.9	.9	¹.9	----
1933	².9	¹.8	².8	.7	1.7	[illegible]	1.2	.6	[illegible]	[illegible]	.6	.9	14.1
1934	1.0	.8	.8	.6	[illegible]	[illegible]	1.3	.4	.7	.7	².6	²1.0	9.7
1935	²1.0	².9	.9	1.0	4.0	7.8	1.6	1.0	1.1	1.2	.9	[illegible]	[illegible]

¹ Estimated.
² Partially estimated.
³ Partial record.

Records as published by U. S. Geological Survey: Previous to October 1913 from Water Supply Paper No. 358; January 1932 to September 1934.
Records from October 1913 to December 1928 from reports of New Mexico State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 167.—*Run-off of Rio Pueblo de Taos near Taos, N. Mex.*

[Drainage area, 67 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1911	¹0.4	0.7	1.3	3.3	9.0	3.6	1.5	1.2	1.0	2.8	1.5	¹1.2	27.5
1912	----	----	[illegible]	2.8	³10.9	[illegible]	.8	.6	.6	[illegible]	¹.5	.5	
1913	¹.6	¹.7	¹.8	1.8	3.5	1.9	.9	.5	.5	.6	.5	.5	12.8
1914	.4	.4	1.0	----	[illegible]	3.6	1.4	1.3	.6	.6	.5	.5	
1915	.5	.4	.8	4.1	8.7	8.1	1.9	1.1	.7	.7	[illegible]	[illegible]	[illegible]
1916	.6	[illegible]	2.0	4.8	----	----	----	----	----	----	----	----	----

¹ Estimated.
² Partial record.
³ 24 days.

Records previous to October 1913 from U. S. Geological Survey Water Supply Paper No. 358.
Records from October 1913 to April 1916 from reports of the New Mexico State engineer.

Table 168.—*Run-off of Rio Taos at Los Cordovas, N. Mex.*

[illegible]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1910				[illegible]	[illegible]	0.7	[illegible]	[illegible]	0.3	[illegible]	[illegible]	[illegible]	
1911	[illegible]	1.3	3.2	5.2	13.3	5.1	[illegible]	1.4	1.5	[illegible]	[illegible]	[illegible]	49.3
1912	[illegible]	[illegible]	4.3	[illegible]	[illegible]	[illegible]	1.3	.5	.7	1.5	1.9	2.3	[illegible]
1913	³1.5	1.6	[illegible]	5.0	4.5	2.8	.4	.5	.7	1.5	1.6	1.2	[illegible]
1914	1.9	1.5	2.4	[illegible]	25.0	6.7	2.4	1.7	1.1	1.5	1.5	1.3	53.8
1915	1.8	2.5	3.1	13.7	30.3	22.3	1.5	1.0	1.0	1.2	[illegible]	2.1	[illegible]
1916	2.8	3.3	5.5	9.1	[illegible]	8.1	1.7	1.9	1.4	2.9	2.0	[illegible]	58.6
1917	2.4	2.0	2.3	2.1	[illegible]	7.2	2.1	.7	.6	.8	1.4	[illegible]	29.1
1918	1.4	[illegible]	3.4	[illegible]	9.5	6.8	1.3	1.0	1.0	1.1	1.3	1.5	[illegible]
1919	1.8	[illegible]	[illegible]	[illegible]	21.5	11.3	6.9	[illegible]	1.8	3.2	[illegible]	[illegible]	[illegible]
1920	2.7	[illegible]	[illegible]	[illegible]	29.4	13.2	.9	[illegible]	[illegible]	[illegible]	.4	[illegible]	63.1
1921	.5	[illegible]	[illegible]	[illegible]	4.6	8.9	3.4	[illegible]	[illegible]	[illegible]	.4	.3	[illegible]
1922	.3	[illegible]	[illegible]	[illegible]	.8	.1	.0	[illegible]	[illegible]	[illegible]	1.2	1.7	7.6
1923	2.1	[illegible]	1.7	[illegible]	6.8	2.6	.5	[illegible]	[illegible]	[illegible]	2.6	2.4	[illegible]
1924	[illegible]	[illegible]	2.6	11.4	19.3	5.6	1.1	[illegible]	[illegible]	1.2	1.6	1.6	51.7
1925	1.5	2.0	3.1	2.5	[illegible]	.3	.3	[illegible]	[illegible]	[illegible]	1.7	1.5	[illegible]
1926	[illegible]							[illegible]		[illegible]	[illegible]	³1.9	
1927	³1.7	³1.6	2.7	6.9	[illegible]	5.1	.8	[illegible]	1.4	[illegible]	[illegible]	³1.5	[illegible]
1928	³2.2	³2.8	³2.4	2.1	14.4	4.1	.3	[illegible]	³.4	³.6	1.3	³1.6	32.6
1929	1.7	[illegible]	3.1	4.6	12.7	[illegible]	.8	[illegible]	4.3	3.3	2.6	2.4	[illegible]
1930	2.2	[illegible]	2.7	7.5	5.1	2.5	2.5	[illegible]	1.1	1.6	1.9	1.9	33.8
1931	1.7	2.1	2.7	2.2	[illegible]	[illegible]	.3	[illegible]	2.2	2.5	³2.0	[illegible]	21.3
1932	[illegible]	[illegible]	5.0	11.2	[illegible]	5.5	2.2	1.7	1.3	1.6	2.0	[illegible]	63.6
1933	³1.7	³1.8	2.5	1.2	[illegible]	[illegible]	1.6	.8	1.0	[illegible]	1.3	[illegible]	[illegible]
1934	[illegible]	³1.7	[illegible]	.9	[illegible]	[illegible]	.3	[illegible]	.6	[illegible]	1.1	1.0	11.0
1935	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	1.4	[illegible]	1.6	1.6	40.7

[illegible]

Table 169.—*Run-off of Rio Lucero near Arroyo Seco, N. Mex.*

[illegible]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1910												[illegible]	
[illegible]	0.4	0.4	0.7	1.5	4.4	[illegible]	[illegible]	2.4	[illegible]	2.7	1.4	[illegible]	24.7
[illegible]			[illegible]	1.0	4.7	5.7	2.5	1.1	.7	[illegible]	.4	.4	
[illegible]	[illegible]	³.4	[illegible]	1.3	2.9	2.6	1.3	.9	.8	1.2	[illegible]	[illegible]	13.7
[illegible]	[illegible]	.3	.8	³1.7	4.7	5.4	2.0	[illegible]	.9	1.0	[illegible]	[illegible]	20.0
[illegible]	.4	.3	.6	2.0	3.1	6.9	3.2	1.6	.7	[illegible]	[illegible]	[illegible]	20.9
[illegible]											[illegible]	³.4	
[illegible]	³.3	³.2	.6	1.3	2.6	1.3	.7	.7	.7	.6	³.4	³.4	9.8
[illegible]	³.4	³.5	[illegible]	1.2	2.6	6.2	[illegible]	1.2	.9	³.7	[illegible]	³.4	17.3

[illegible] Record as published by U. S. Geological Survey: Previous to October 1913 from Water Supply Paper No. 358; November 1933 to September 1934.
[illegible]
[illegible] Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

Table 170.—*Run-off of Rio Fernando de Taos near Taos, N. Mex.*

[illegible]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1912										[illegible]	121	105	
1913	[illegible]	[illegible]	269	1,340	[illegible]	672	[illegible]	133	111	[illegible]	177	66	[illegible]
1914	141	127	[illegible]	[illegible]	3,720	[illegible]	[illegible]	497	245	[illegible]	178	165	9,313
1915	182	160	[illegible]	2,710	[illegible]	2,330	[illegible]	[illegible]	[illegible]	[illegible]	182	143	[illegible]
1916	[illegible]	[illegible]	967	[illegible]	4,260	706	[illegible]	[illegible]	[illegible]	[illegible]	142	91	10,191
1917	123	125	[illegible]	434	1,100	[illegible]	[illegible]	[illegible]	44	47	[illegible]	19	2,790
1918	11	47	[illegible]	[illegible]	1,520	[illegible]	[illegible]	107	112	152	[illegible]	152	4,353
1919	123	79	169	[illegible]	5,500	[illegible]	1,110	[illegible]	372	[illegible]	220	239	13,836
1920	[illegible]	350	531	1,620	[illegible]	1,630	[illegible]	490	248	[illegible]	157	146	10,599
1921	[illegible]	289	380	[illegible]	1,470	[illegible]	[illegible]	752	271	[illegible]	[illegible]	[illegible]	6,872
1922	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	170	[illegible]	150	27	22	38	58	4,295
1923	[illegible]	[illegible]	330	[illegible]	[illegible]	190	82	38	47	[illegible]	326	[illegible]	[illegible]
1924	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	312	305	110	44	[illegible]	13	[illegible]	[illegible]
1925	110	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	106	[illegible]	[illegible]	[illegible]	101	87	1,758
1926	78	81	209	3,197	7,853	2,108	190	123	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1927	72	123	[illegible]	893	[illegible]	[illegible]	[illegible]	[illegible]	115	[illegible]	61	[illegible]	[illegible]
1928	³102	137	[illegible]	1,097	2,707	322	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

TABLE 171.—*Run-off of Embudo Creek at Dixon, N. Mex.*

[Drainage area [illegible] square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1923										5.3	[illegible]	[illegible]	
1924	2.4	[illegible]	[illegible]	18.0	[illegible]	[illegible]	[illegible]	.2	1.7	2.6	[illegible]	[illegible]	70.8
1925	[illegible]	2.8	2.6	5.1	2.3	1.6	6.3	5.8	4.7	[illegible]	2.4	1.9	42.8
1926	[illegible]	[illegible]	[illegible]	[illegible]	13.8	[illegible]	3.2	[illegible]	[illegible]	2.6	1.7	1.6	50.0
1927	[illegible]	1.7	3.1	15.3	16.3	5.3	[illegible]	1.0	2.6	2.6	1.8	1.6	[illegible]
1928	[illegible]	1.4	2.0	8.4	21.4	[1] 9.3	[1] [illegible].8	3.1	1.1	1.8	2.1	1.7	51.8
1929	[illegible]	1.2	1.9	5.7	19.5	8.5	[1] 3.8	[1] 9.8	11.3	5.2	3.5	3.2	75.2
1930	2.0	1.6	1.7	[illegible]	8.6	[illegible]	[1] 5.7	6.2	2.0	2.0	1.6	1.7	[illegible]
1931	[illegible]	[illegible]	2.0	6.6	18.1	7.7	2.2	1.9	5.4	[illegible]	[1] 2.7	[1] 2.7	[illegible]
1932	[illegible]	4.2	6.7	21.9	[illegible]	[1] 11.2	[1] 3.0	4.8	3.1	3.6	2.1	1.5	90.5
1933	1.7	1.3	1.2	[illegible]	[illegible]	[1] 14.1	[1] 3.1	[1] 1.9	1.1	1.7	1.7	2.0	[illegible]
1934	1.7	1.2	1.4	2.2	1.9	[illegible]	.3	.5	[illegible]	1.3	1.1	1.5	[illegible]
1935	[illegible]	1.5	2.3	9.1	30.0	[illegible]	5.3	9.0	6.1	[illegible]	1.9	2.0	102.8

[1] Partially estimated.

Records from October 192[illegible] to September 1930 from reports of the New Mexico State engineer.
Records from October 1930 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 172.—*Run-off of Rio Chama at Chama, N. Mex.*

[Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1912									(1)	1.8	1.5	0.9	
1913	[2] 0.8	[2] 0.6	1.1	13.9	25.5	12.4	3.0	1.6	1.4	2.1	1.6	1.3	65.3
1914	[2] .7	[2] .9	3.8	18.7	47.7	23.0	6.7	3.9	4.0	7.0	3.2	1.8	121.4
1915	[2] 1.[illegible]	[2] 1.2	[2] 2.8	22.6	38.2	35.8	10.9	3.4	2.0	1.3	(1)		
1916			(1)	29.2	62.1	34.3	11.5	5.5	3.2				

[1] Partial record.
[2] Estimated.

Records previous to October 1913 from U. S. Geological Survey Water Supply Paper No. [illegible].
Records from October 1913 to September 1916 from reports of New Mexico State engineer.

TABLE 173.—*Run-off of Rio Chama at Park View, N. Mex.*

[Drainage area 405 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1912											(1)	2.0	
1913	[2] 1.8	[2] 2.5	4.3	48.6	86.1	26.1	[illegible]	2.1	2.4	4.6	[illegible]	3.3	[illegible]
1914	[2] 3.1	[2] 3.0	9.1	50.8	133.0	48.6	12.9	7.3	7.0	12.2	[illegible]	4.1	297.5
1915	[2] 3.5	[2] 2.8	[2] 6.2	41.8	101.0	94.0	20.7	[illegible]	3.7	2.7	[illegible]		
1925	[2] 3.7	[2] 2.5	[2] 18.4	[3] 107.0	61.9	[3] 16.9	5.3	9.7	5.1	10.7	[illegible]	[illegible]	[illegible]
1926	[3] 3.8	[2] 3.1	[3] 5.0	46.4	188.0	61.0	12.3	4.1	1.7	3.7	[illegible]	[3] 3.9	336.3
1927	[3] 3.8	[3] 4.2	11.5	95.8	[illegible]	59.6	21.7	[illegible]	28.7	16.7	[3] 9.0	[3] 5.5	[illegible]
1928	[2] 4.3	[illegible]	[3] 13.3	[3] 42.8	[3] 119.0	[3] 26.8	[3] 5.0	[3] 3.8	[3] 2.1	[illegible]	[3] 1.6	[2] 1.5	226.6
1929	[illegible]	[2] 2.2	[3] 6.0	[3] 55.2	119.0	33.0	[3] 8.8	20.5	[3] 26.0	10.3	[3] 6.2	[3] 4.3	287.3
1930	[3] 4.0	[3] 4.3	[3] 8.9	[3] 92.2	[3] 73.4	[3] 32.5	12.1	9.1	[3] 2.7	4.2	[3] 2.5	[3] 2.3	248.2
1931	[2] 2.1	[2] 3.1	[2] 4.3	18.3	54.4	12.6	1.9	2.0	4.8	7.0	[3] 4.4	[3] 5.6	[illegible]
1932	[2] 6.1	[2] 8.3	11.9	84.9	235.0	[3] 73.9	20.9	6.6	3.2	3.1	2.4	[3] 2.6	458.9
1933	[2] 2.8	[2] 2.5	[3] 5.0	[3] 21.5	[3] 92.2	60.4	[3] 11.2	[3] 4.7	[3] 5.7	[3] 5.4	3.1	[3] 3.4	217.9
1934	[illegible]	2.9	8.6	42.2	17.6	[3] 2.8	0.9	[illegible]	2.2	1.5	[illegible]	1.4	85.2
1935	2.0	2.5	4.8	39.7	133.0	114.0	17.6	8.9	6.6	5.2	3.1	2.8	340.2

[1] Partial Record.
[2] Estimated.
[3] Partially estimated.

Records as published by U. S. Geological Survey. Previous to October 1913 from Water Supply Paper No. [illegible], October 1930 to September 1934 [illegible].
Records from October 1913 to September 1930 from reports of New Mexico State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 174.—*Estimated run-off of Rio Chama above El Vado Reservoir, N. Mex.*

[Drainage area 875 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in per cent of mean
1890 [1]	2.1	2.8	6.0	126.0	185.0	70.0	14.0	13.0	7.0	7.0	4.1	3.9	440.9	133.8
1891 [1]	4.3	4.4	20.0	144.0	214.0	80.0	16.0	14.0	6.0	24.0	5.0	3.8	535.5	162.5
1892	3.2	4.4	20.0	176.0	184.0	62.0	10.0	2.0	0	1.9	2.9	1.6	468.0	142.0
1893	.4	0	0	83.0	137.0	58.0	9.0	3.2	3.5	4.2	1.9	2.8	303.0	[illegible]
1894	[1] .2	[1] 0	[2] 5.0	[2] 80.0	[2] 120.0	[2] 28.0	[2] 8.0	[2] 2.0	[2] 2.0	[1] 0	[1] 4.3	[1] 4.3	[illegible]	77.0
1895	[1] 2.6	[3] .9	[3] 19.0	[3] 109.0	[3] 101.0	[3] 78.0	[3] 18.0	[3] 12.0	[3] 4.3	[3] 7.0	[3] 4.8	[3] 3.9	360.5	[illegible]
1896	2.4	0	10.0	72.0	63.0	14.0	7.0	0	3.7	4.3	3.1	3.2	182.7	55.4
1897 [1]	2.5	2.0	12.0	146.0	220.0	76.0	13.0	5.0	8.0	23.0	2.6	0	510.1	154.8
1898	0	0	0	97.0	63.0	23.0	3.0	[illegible]	0	2.9	5.0	4.3	205.2	62.3
1899	.1	2.6	17.0	79.0	55.0	13.0	12.0	6.0	12.0	3.0	4.8	3.8	208.3	63.2
1900 [1]	3.9	1.3	[illegible]	17.0	60.0	37.0	1.0	[illegible]	10.0	5.0	4.0	3.7	147.5	44.7

See footnotes at end of table.

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TABLE 174.—*Estimated run-off of Rio Chama above El Vado Reservoir, N. Mex.*—Continued

Year	[illegible]	February	[illegible]	[illegible]	[illegible]	June	July	[illegible]	[illegible]	October	November	December	Annual	Annual run-off in percent of mean
1901 [2]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13.0	12.0	7.0	1.0	3.2	2.5	223.5	67.8
[illegible]	[illegible]	[illegible]	[illegible]	42.[illegible]	[illegible]	2.0	5.0	10.0	7.0	2.0	2.8	2.5	99.7	30.2
[illegible]	[illegible]	[illegible]	12.0	82.0	[illegible]	117.0	28.0	4.8	1.6	1.5	0	3.6	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[3] 3.0	[4] 6.0	[4] 18.0	[4] 24.0	[4] 52.0	[illegible]	[4] 1.9	143.8	43.6
[illegible]	6.0	11.0	42.0	91.0	182.0	66.0	[illegible]	6.0	3.5	4.2	5.0	[illegible]	429.6	[illegible]
[illegible]	[illegible]	[6] 5.0	[6] 8.0	[6] 70.0	[illegible]	[6] 78.0	[6] 16.0	[6] 11.0	[6] 7.0	[6] 13.0	[6] 7.0	[6] 3.0	409.0	124.1
[illegible]	[illegible]	7.0	21.0	141.0	145.0	101.0	35.0	26.0	8.0	9.0	5.0	[illegible]	[illegible]	154.3
[illegible]	[7] 5.0	[7] 4.0	[6] 26.0	[6] 62.0	[6] 108.0	[6] 48.0	[6] 11.0	[6] 12.0	[6] 4.8	[6] 6.0	[6] 3.6	[6] 1.8	292.2	[illegible]
1909	[6] 6.0	[6] 6.0	[6] 10.0	[6] 91.0	[6] 163.0	[6] 79.0	[6] 15.0	[6] 13.0	[illegible]	[6] 7.0	[6] 0	[6] .3	401.3	121.8
[illegible]	[illegible]	[6] 1.7	[6] 51.0	[6] 97.0	[illegible]	[6] 44.0	[6] 0	[6] 3.5	[6] 1.7	[6] 0	[6] 3.6	[6] 1.4	334.4	101.5
[illegible]	[illegible]	[6] 6.0	[6] 27.0	[6] 67.0	[6] 144.0	[6] 52.0	[illegible]	[6] 7.0	[6] 4.1	[6] 47.0	[7] 4.7	[7] 5.0	[illegible]	121.6
[illegible]	[illegible]	[6] 7.0	[6] 22.0	[illegible]	[6] 184.0	[6] 101.0	[6] 7.0	[6] 8.0	[6] 4.8	[3] 5.0	[3] 2.8	[3] 3.4	399.5	121.2
[illegible]	[illegible]	[8] 2.7	[8] 5.0	[8] 52.0	[8] 88.0	[8] 28.0	[8] 5.0	[8] 2.5	[illegible]	5.1	3.3	3.6	[illegible]	60.9
[illegible]	3.4	[illegible]	9.4	54.7	132.0	53.6	14.2	7.5	[illegible]	14.6	[illegible]	4.4	311.4	[illegible]
[illegible]	4.0	3.3	10.9	78.0	123.0	94.6	18.2	8.0	[illegible]	2.7	1.3	[8] 4.1	[illegible]	106.8
[illegible]	[illegible]	[8] 4.5	[8] 85.0	[10] 78.0	170.0	[illegible]	21.7	[illegible]	[illegible]	[8] 31.0	[8] 8.0	[8] 4.5	[illegible]	157.7
[illegible]	[illegible]	4.0	14.0	47.0	125.0	99.0	21.0	[illegible]	1.5	1.0	2.8	3.2	330.2	100.2
[illegible]	[illegible]	3.1	15.0	20.0	114.0	35.0	10.0	2.8	2.5	2.8	3.3	3.9	214.3	[illegible]
[illegible]	[illegible]	3.1	[illegible]	80.0	147.0	46.0	38.0	12.0	1.8	8.0	6.0	5.0	376.7	114.3
[illegible]	[illegible]	[illegible]	32.6	59.4	183.0	127.0	56.7	18.0	4.0	[illegible]	4.5	2.4	[illegible]	154.8
[illegible]	3.1	4.2	13.0	21.9	119.0	68.3	11.7	19.7	7.8	5.8	3.6	2.8	[illegible]	85.2
[illegible]	3.0	4.8	31.4	[illegible]	197.0	66.5	7.2	[illegible]	2.9	3.0	4.2	6.1	[illegible]	116.4
[illegible]	7.3	7.8	10.5	36.7	149.0	61.5	12.6	13.7	23.8	15.2	8.5	4.9	351.5	106.6
[illegible]	6.8	9.6	36.0	105.0	178.0	47.3	12.4	4.1	2.0	4.2	3.3	3.4	[illegible]	125.1
[illegible]	[illegible]	3.0	15.0	76.0	57.0	19.0	7.0	11.0	6.0	13.0	9.0	7.0	227.4	[illegible]
[illegible]	4.4	3.5	[illegible]	55.0	198.0	73.0	11.0	3.7	1.7	3.8	3.8	4.1	368.0	111.7
[illegible]	[illegible]	4.5	14.0	102.0	186.0	[illegible]	24.0	10.0	33.0	17.0	10.0	6.0	[illegible]	144.2
[illegible]	5.0	5.0	14.0	43.0	128.0	28.0	4.8	4.2	1.9	1.5	1.9	1.8	239.1	72.6
[illegible]	2.1	2.8	9.0	67.0	127.0	33.0	10.0	28.0	22.0	10.0	7.0	[illegible]	322.6	97.9
[illegible]	1.4	5.0	[illegible]	101.0	77.0	33.0	13.0	10.0	2.6	4.4	[illegible]	[illegible]	265.2	[illegible]
1931 [illegible]	2.3	3.6	[illegible]	22.0	58.0	13.0	2.1	2.1	7.0	12.0	5.0	4.8	[illegible]	41.8
[illegible]	6.0	10.0	[illegible]	109.0	246.0	[illegible]	21.0	8.0	3.3	3.5	2.8	[illegible]	[illegible]	[illegible]
[illegible]	3.0	[illegible]	[illegible]	23.0	98.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	235.7	71.5
1934 [illegible]	3.4	3.5	[illegible]	43.0	18.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	96.2	29.2
[illegible]	[illegible]	[8] 3.0	[8] 7.0	[8] 45.0	[8] 141.0	[8] [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.4	364.6	[illegible]
Mean	3.8	[illegible]	16.2	72.7	130.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.1	[illegible]	329.5	
Percent of annual	1.15	[illegible]	[illegible]	22.06	39.61	17.15	4.22	[illegible]	[illegible]	[illegible]	[illegible]	1.03	[illegible]	

[illegible] Otowi Bridge, estimated; [3] actual records; [illegible]

[illegible]

[illegible] from October 1913 to December 1924 for station "near Tierra Amarilla" from reports of New Mexico State engineer.

[illegible] for November and December 1935 are provisional records furnished by U. S. Geological Survey for new station "below El Vado Dam, near Tierra Amarilla" corrected for storage.

TABLE 175.—*Run-off of Rio Chama near Chamita, N. Mex.*

[Drainage area 3,202 square miles. Unit, 1,000 acre-feet]

Year	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	August	[illegible]	[illegible]	November	[illegible]	Annual
1912											[illegible]	[illegible]	
[illegible]	[illegible]	[3] 3.9	[illegible]	73.2	100.0	[illegible]	10.7	4.8	9.9	9.3	[illegible]	5.4	279.1
[illegible]	[illegible]	10.5	38.5	94.6	175.0	44.7	43.5	18.5	12.6	21.2	11.1	5.8	483.1
[illegible]	[3] 4.2	[illegible]	[illegible]	134.0	213.0	219.0	30.4	14.0	7.1	2.0	3.6	[illegible]	[illegible]
[illegible]	[illegible]	13.4	[illegible]	[illegible]	[illegible]	86.1	26.7	35.7	9.1	43.4	14.7	8.8	907.2
[illegible]	9.0	[illegible]	23.1	[illegible]	146.0	141.0	40.4	8.1	3.8	2.4	3.5	5.0	479.6
[illegible]	(1)	(1)	[illegible]	39.9	[illegible]	37.2	(1)	4.1	5.3	4.7	4.5	7.1	[illegible]
[illegible]	[illegible]	5.4	38.8	[illegible]	[illegible]	55.6	80.5	24.4	4.3	12.1	9.7	11.3	618.9
[illegible]	10.0	37.1	53.9	120.0	313.0	141.0	61.5	19.4	8.3	9.2	7.7	5.2	786.4
1921	8.2	10.0	33.1	36.2	118.0	[illegible]	[illegible]	37.0	15.0	10.6	7.6	[illegible]	429.4
[illegible]	7.2	[illegible]	[illegible]	48.6	126.0	82.9	[illegible]	4.5	.3	1.6	5.2	8.0	341.4
1923	7.7	[illegible]	31.8	[illegible]	[illegible]	69.5	34.5	27.0	[illegible]	20.0	[illegible]	10.3	[illegible]
1924	6.5	45.0	24.3	202.0	[illegible]	78.6	14.2	6.8	3.8	8.6	[illegible]	6.0	744.0
1925	5.9	10.4	23.6	122.0	91.4	16.1	12.1	16.9	4.7	13.8	8.9	8.0	333.8
[illegible]	7.6	5.6	13.4	[illegible]	255.0	[3] 142.0	[3] 2.0	[3] 1.2	1.5	4.5	6.4	5.3	549.5
1927	4.8	6.1	29.7	138.0	301.0	96.0	34.5	12.9	55.5	19.4	[3] 12.7	[3] 11.4	722.0
[illegible]	[3] 9.2	8.1	21.4	46.9	[3] 179.0	[illegible]	[illegible]	[illegible]	[3] .6	[3] 1.1	[3] 3.7	[3] 3.6	316.8
[illegible]	[illegible]	[illegible]	23.4	131.0	170.0	[illegible]	[3] 15.1	[3] 70.4	35.9	11.6	[3] 11.0	[3] 7.1	517.6
1930	[illegible]	9.8	[illegible]	150.0	[illegible]	34.0	[3] 19.8	14.1	2.2	[3] 5.5	3.5	[3] 1.7	[illegible]
1931	[illegible]	[illegible]	13.2	41.2	77.0	13.8	3.5	3.0	20.2	40.1	[3] 8.3	[illegible]	[illegible]
1932	[illegible]	[illegible]	63.9	246.0	306.0	81.3	20.7	13.7	[illegible]	[illegible]	4.9	[3] 4.1	778.6
[illegible]	[illegible]	[illegible]	14.2	31.2	[3] 128.0	[3] 84.7	[3] 22.0	[3] 11.9	[3] 11.9	7.1	3.7	5.5	329.3
[illegible]	[illegible]	[illegible]	11.2	47.9	[illegible]	[3] 4.2	[3] 1.5	[3] 0.6	7.4	1.4	1.8	[illegible]	109.7
1935	[illegible]	[illegible]	[illegible]	33.5	89.4	[illegible]	13.3	[illegible]	31.6	[illegible]	[illegible]	[illegible]	411.9

[illegible]

TABLE 176.—*Run-off of El Rito Creek near El Rito, N. Mex.*

[Drainage area 52 square miles. Unit, acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
[illegible]					(1)	[illegible]	[illegible]	[illegible]	174	210	[illegible]	[illegible]	[illegible]
[illegible]	61	169	[illegible]	7,720	8,110	[illegible]	[illegible]	179	81	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	²97	²98	²276	1,210	3,780	[illegible]	[illegible]	113	[illegible]	89	[illegible]	²123	7,181
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	338	81	[illegible]	[illegible]	73	[illegible]	[illegible]	85	2,376
[illegible]	127	129	[illegible]	4,100	7,340	1,430	186	[illegible]	[illegible]	102	89	62	[illegible]

¹ Partial record.
² Partially estimated.
³ Estimated.

Records from May [illegible] to September [illegible] from reports of U. S. Geological Survey.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 177.—*Run-off of Rio Ojo Caliente at La Madera, N. Mex.*

[Drainage area 344 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1932				[illegible]	33.6	¹3.8	1.0	1.3	[illegible]	¹0.6	[illegible]	²0.7	
1933	¹0.8	²1.1	¹1.2	[illegible]	¹20.1	[illegible]	¹1.2	[illegible]	.4	.6	.8	¹.9	38.8
1934	¹.9	1.0	2.3	3.2	1.2	.4	.4	.2	.3	[illegible]	[illegible]	.8	11.8
1935	1.4	1.1	1.9	14.1	21.4	7.1	.9	1.1	.7	[illegible]	.9	.9	52.1

¹ Partially estimated.
² Estimated.

Records from April 1932 to September 1933 from reports of U. S. Geological Survey.
Records from October 1933 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 178.—*Run-off of Rio Vallecitos at Vallecitos, N. Mex.*

[Drainage area 115 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1911				[illegible]		(¹)	2.3	0.5	0.5	2.1	1.3	[illegible]	
1912				[illegible]	32.9	4.9	.7	.3	.2	.3	.2	²0.3	
1913			0.6	13.0	10.4	1.7	.4	.7	.4	.6	.5	².4	
1914	²0.4	²0.4	1.3	11.5	18.8	2.3	1.0	2.2	.2	1.7	1.1	².6	41.5

¹ Partial record.
² Estimated.

Records previous to October 1913 from U. S. Geological Survey. Water Supply Paper No. 358.
Records from October 1913 to December 1914 from reports of the New Mexico State engineer.

TABLE 179.—*Run-off of Rio Santa Cruz at Cundiyo, N. Mex.*

[Drainage area 86 square miles. Unit, acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1928						2,154	518	767	323	295	316	395	
1929	385	310	441	1,755	4,539	2,913							
1930									¹936	[illegible]	¹900	¹964	
1931	¹736	621	¹1,120	3,260	4,630	3,430	1,440	¹1,110	5,030	2,230	¹1,060	[illegible]	26,087
1932	²1,100	889	2,530	7,760	10,400	4,650	2,080	1,990	1,260	1,010	[illegible]	[illegible]	34,971
1933	²490	²530	[illegible]	936	2,470	3,370	2,080	[illegible]	¹956	[illegible]	574	¹496	14,832
1934	[illegible]	421	678	1,160	1,450	607	498	695	985	[illegible]	460	474	8,553
1935	¹450	461	1,050	2,550	8,440	9,500	2,160	2,950	2,100	1,100	829	837	32,427

¹ Partially estimated.
² Estimated.

Records from June 1928 to September 1931 from reports of the New Mexico State engineer.
Records from October 1931 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 180.—*Run-off of Nambe Creek near Nambe, N. Mex.*[1]

[Drainage area 37 square miles. Unit, acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1932										415	²328	²157	
1933	[illegible]	[illegible]	²261	[illegible]	²1,143	1,413	571	438	525	[illegible]	247	²192	5,956
1934	152	130	[illegible]	400	551	[illegible]	²133	²392	679	[illegible]	[illegible]	[illegible]	3,720
1935	²396	²197	292	[illegible]	1,985	4,019	1,028	1,350	1,251	574	375	307	12,390

¹ Includes the diversion by Nambe canal above the station.
² Partially estimated.

Records from U. S. Geological Survey; those from October 1934 to December 1935 are provisional.

TABLE 181.—*Run-off of Santa Fe Creek near Sante Fe, N. Mex.*

[illegible]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
[illegible]	[illegible]	[illegible]	0.1	0.6	1.0	1.4	0.7	0.4	0.3	0.3	0.2	0.3	[illegible]
[illegible]	.2	.2		1.1	1.8	1.0	1.6	1.0	.4	.4	.4	[illegible]	8.8
1915	[illegible]	[illegible]		4.1	2.6	2.2	1.2	.6	.2	.2	.2	[illegible]	12.5
[illegible]	[illegible]	[illegible]	1.8	2.4	3.4	1.8	.8	[illegible]	.3	.6	.3	.2	13.3
[illegible]	[illegible]	[illegible]			.6	.6	.2	.1	.1	.1	.1	.1	2.6
[illegible]		.1		.6	1.2	1.0	.5	[illegible]	.2	.1	[illegible]	[illegible]	[illegible]
[illegible]			.6	3.6	[illegible]	[illegible]	3.5	1.7	.7	[illegible]	.3	.3	[illegible]
[illegible]	[illegible]	[illegible]	.4	.9	2.8	1.3	.3	.2	.1	.1	.2	[illegible]	7.0
[illegible]		[illegible]	.3	.5	1.9	[illegible]	3.1	6.1	1.0	.2	[illegible]	.2	18.3
[illegible]	[illegible]		.3	.9	1.0	.5	.2	.1	.1	.0	.1		[illegible]
[illegible]			.3		1.7	.9	.2	.3	.2	.2	.3	.2	5.2
[illegible]	.1	.1	.5	4.2	3.9	1.2	.3	.2	.1	.1	[illegible]	.1	10.9
[illegible]	.1	.1	.2	.3	.2	.1	[illegible]	.2	.2	.2	[illegible]	.1	[illegible]
[illegible]		[2].1	.4	[1]1.2	4.3	[1]2.3	[illegible]	.2	.2		.1	.2	[illegible]
[illegible]	[2].1	.0	.3	.7	1.6	.4	.2	[illegible].3	.3				[illegible]
[illegible]	[2].1	[illegible]	.1	[illegible]	1.8	.6	.2	.4	.5				[illegible]
[illegible]			.2	[illegible]	1.9	1.1	[illegible].4	1.3	[illegible]	[illegible]	.3	[illegible].2	8.8
[illegible]			.3	1.0	.8	.5		1.0	.3	.2	[2].1	[2].1	5.4
[illegible]	[illegible]	[illegible]	[2].2		[illegible]	1.0	.3	.2	1.7	.9	[2].2	.1	[illegible]
[illegible]	[illegible]	[illegible]	.7	[illegible]	2.0	.8	.4	.4	.5		.1		[illegible]
[illegible]	.1	.1	.1		[illegible]	.7	.4		.1		.1		[illegible]
[illegible]	.1		.1			.2	.2	[illegible]	.2		.1		[illegible]
[illegible]	.1	[illegible]	.2	[illegible]	[illegible]	1.6	.4	[illegible]			[illegible]		6.5

[illegible]

Records as published by U. S. Geological Survey: Previous to October 1913 from Water Supply Paper No. 358; October 1913 to December 1914; October 1930 to September 19[illegible]

[illegible]

TABLE 182.—*Run-off of Arroyo Hondo near Santa Fe, N. Mex.*

[illegible]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
[illegible]		[illegible]	[illegible]	84	14	[illegible]	[illegible]	12	[illegible]	12	[illegible]	0	
1914	[illegible]	[illegible]	[illegible]	24	36	126	159	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	592
[illegible]	[illegible]	[illegible]	[illegible]	892	331	139	[illegible]	102	[illegible]	[illegible]	[illegible]	[illegible]	2,239
[illegible]	[2]12	(1)	584	[illegible]	45	8	129	(1)	[illegible]	200	74	[illegible]	
[illegible]	[illegible]	10	[illegible]	12	[illegible]	1	1	1	0	0		0	
[illegible]	0	14	[illegible]	[illegible]	[illegible]	[illegible]	1	0	[illegible]	2	3	[illegible]	175
[illegible]	11	17	[illegible]	507	[illegible]	[illegible]	293	[illegible]	[illegible]	42	[illegible]	37	1,418
1920	15	[illegible]	[illegible]	12	17	[illegible]	[illegible]	0	[illegible]	4	[illegible]	12	124
[illegible]	13	[illegible]	[illegible]	69	47	62	[illegible]	121	74	[illegible]	9	[illegible]	[illegible]
[illegible]	[illegible]	11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				

[illegible]

Records previous to October 1913 from U. S. Geological Survey Water Supply Paper No. 358.
Records from October 1913 to September 1922 from reports of New Mexico State engineer.

TABLE 183.—*Run-off of Rio Puerco at Rio Puerco, N. Mex.*

[illegible] area 4,795 square miles. [illegible]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
[illegible]	0	[illegible]	[illegible]	1.0	0	1.3	0.3	4.4	3.6	[illegible]	1.9	[illegible]	[illegible]
[illegible]	[illegible]	16.2	4.6	3.6	3.8	.9	52.0	18.8	3.2	11.9	.2	1.7	[illegible]
[illegible]	.9	2.8	19.7	[illegible]	9.2	[illegible]	[1]87.1	11.8	15.5	.1	.2	.7	229.3
1916	4.3	6.8	21.4	6.4	[illegible]	[illegible]	19.6	48.3	.8	27.8	.2	1.4	141.9
1917	2.1	.2	.3	[illegible]	[illegible]	[illegible]	1.3	3.0	15.3	0	.1	.1	22.4
[illegible]	1.4	1.4	1.6	0	.1	[illegible]	9.1	2.5	.2	[illegible]	.9	.9	23.0
[illegible]	.8	3.5	18.1	31.3	[illegible]		[illegible]	24.7	[illegible]	4.1	1.6	10.2	[illegible]
[illegible]	[illegible]	9.2	4.5	8.4	[illegible]	[illegible]	[illegible]	1.7	[illegible]	.2	.5	0	41.3
1921	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	27.6	[illegible]	1.0	1.1	.1	
[illegible]	.1	.1	.2	0	[illegible]	[illegible]	[illegible]	1.5	.9		.2	.2	[illegible]
[illegible]	0	[illegible]	0	[illegible]	0	[illegible]	.2	3.2	2.3	.1	2.2	.2	[illegible]
[illegible]	.2	.3	2.1	11.6	5.4		3.8	0	7.4	[illegible]	.1	1.0	34.9
[illegible]	2.3	[illegible]	.1	.1	[illegible]	[illegible]	(4)	[illegible]	(4)	[illegible]	.6	[illegible]	
[illegible]									[illegible]	1.1	[1].2	.9	
[illegible]	2.0	[illegible]	14.3	23.8	[illegible]	4.5	[illegible]	[illegible]	[illegible]	.2	.4	[illegible]	[illegible]
[illegible]			0	[illegible]	1.3	.7	.9	[1]12.3	[illegible]	.2	[illegible]	[illegible]	
[illegible]	2.6	1.1	[illegible]	[illegible]	5.3	[illegible]	0	71.4	24.3	.2	.2	[illegible]	[illegible]

[illegible]

TABLE 184.—*Run-off of Bluewater Creek near Bluewater, N. Mex.*

[Drainage area 23[illegible] square miles. Unit, acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1912							(1)	46	71	0	4	[illegible]	
1913	0	0	513	4,780	69	46	58	14	365	307	101	[illegible]	[illegible]
1914	[illegible]	124	6,040	1,990	177	30	604	389	192	189	84	[illegible]	10,750
1915	[illegible]	[2] 227	8,140	10,800	[illegible]	2,900	721	[illegible]	[illegible]	237	[illegible]	[3] 398	28,375
1916	(1)		(1)	7,620	144	167	945	1,700	694	[3] 2,970	591	246	
1917	216	229	808	1,040	800	60	109	11	53	44	20	8	[illegible]
1918	6	1,230	2,410	149	39	168	177	195	30	37	35	24	[illegible]
1919	12	56	3,200	8,670	280								
1921				(1)	37	37	2,260	1,650	296	131	82	61	
1922	129	440	319	267	36	6	8	2	15	21	67	180	1,540
1923	170	600	2,960	2,460	332	13	210	480	1,[illegible]	101	670	1,015	10,377
1924	1,620	2,610	547	1,015	601	46	43	57	35	44	23	68	7,109
1925	238	1,040	944	66	20	20	32	94	152	218	148	171	[illegible]
1926	145	189	[3] 12,128	[3] 8,767	[3] 1,672	[3] 141	8	[3] 305	[illegible]	[illegible]	[3] 48	[3] 274	24,462
1927	[3] 381	143	[3] 8,848	10,744	1,408	1,0[illegible]	797	[illegible]	[3] 121	[3] 117	15	[3] 30	23,770
1928	[illegible]	[3] 40	[3] 48	88	157	1,550	518	84	[illegible]	93	[3] 125	[3] 166	2,894
1929	460	[3] 22	[3] 37	198	1,366	866	287	438	219	311	[3] 280	[3] 206	4,390
1930	307	[3] 247	269	371	2,300	1,160	1,770	848	477	107	[3] 132	[3] 160	8,248
1931	114	[3] 22	52	348	792	1,350	508	211	355	27	[3] 29	[3] 33	3,841
1932	[3] 15	51	[3] 424	942	1,980	3,160	4,990	1,470	[3] 691	[3] 713	[3] 510	[3] 292	12,241
1933	105	451	399	1,370	2,130	1,930	2,500	1,760	[3] 309	272	290	[3] 139	11,955
1934	[3] 147	117	126	713	2,280	788	54	29	24	25	[3] 12	[3] 28	4,373
1935	28	[3] 13	64	164	1,290	3,450	2,860	823	[3] 320	[3] 264	193	[3] 118	9,797

[1] Partial record.
[2] Estimated.
[3] Partially estimated.

Records as published by U. S. Geological Survey. Previous to October 1913 from Water Supply Paper No. 358, October 1913 to December 1914, October 1930 to September 1934. Records from January 1915 to September 1930 from reports of the New Mexico State engineer. Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 185.—*Run-off of Bluewater Creek at Grants, N. Mex.*

[Unit acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1913	0	0	41	1,950	0	0	19	0	22	310	4	0	2,346
1914													
1915		(1)	(1)	(1)	1,380	110	282	187	132	2	0	0	
1916	(1)	1,290	12,600	5,750	56	6	138	574	65	659	52	5	
1917	0	11	40	13	136	21	12	13	12	12	9	5	284
1918	0	202	497	4	7	26	26	10	9	19	15	7	822
1919	1	4	680	4,100	8	4	5,740	1,280	651	14	11	228	12,721
1920	860	5,100	4,160	7,920	260	91	18	18	12	12	9	6	18,466
1921	11	11	12	12	(1)			(1)	70	19	18	16	
1922	12	90	12	18	9	53	0	0	0	7	13	24	238
1923	16	8	358	262	6	6	102	2,690	3,000	27	316	941	7,732
1924	223	39	265	2,510	56	8	14	132	121	9	6	26	3,409
1925	22	6	6	6	1	1	28	10	153	1	0	0	234
1926	0	0	0	357	183				0	0	0	0	

[1] Partial record.

Records previous to October 1913 from U. S. Geological Survey Water Supply Paper No. 358.
Records from October 1913 to December 1926 from reports of the New Mexico State engineer.

TABLE 186.—*Run-off of San Jose River near Suwanee, N. Mex.*

[Drainage area 2,765 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1910	.....	.....							(1)	0.4	0.2	(1)	.....
1911	.....	.....											.....
1912	0.5	0.2	0.9			(1)	(1)	(1)	(1)	1.1	.4	0.1	.....
1913	[2] .2	[2] .3	.5	1.9	0.2	1.8	0.3	0.6	0.7	1.2	.4	.3	[illegible]
1914	.5	.2	2.5	1.0	1.2	.4	5.8	3.3	1.6	3.3	.5	.8	21.1
1915	.6	1.1	3.1	9.5	[3] 2.6	.3	[3] 11.4	2.1	2.0	.2	.2	.2	33.3
1916	2.7	4.3	12.0	8.1	1.4	.7	2.7	(1)	.3	6.0	.6	.6	.....
1917	1.4	.9	.3	.2	.2	.2	.6	1.3	(1)				.....

[1] Partial record.
[2] Estimated.
[3] Partially estimated.

Records previous to October 1913 from U. S. Geological Survey Water Supply Paper No. 358.
Records from October 1913 to September 1917 from records of the New Mexico State engineer.

TABLE 187.—*Discharge of Rio Grande below Elephant Butte Dam, N. Mex.*

[illegible]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in per cent of mean
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	117.0	77.1	21.2	14.1	23.5	895.9	104.2
1916	1.6	[illegible]	[illegible]	107.0	[illegible]	192.0	[illegible]	[illegible]	67.3	110.0	55.6	115.0	1,125.4	130.8
[illegible]	[illegible]	107.0	109.0	102.0	124.0	138.0	191.0	111.0	110.0	109.0	[illegible]	52.7	[illegible]	151.6
[illegible]	[illegible]	[illegible]	[illegible]	89.8	94.1	95.2	90.4	77.5	[illegible]	33.6	19.9	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	22.2	[illegible]	75.0	[illegible]	112.0	[illegible]	91.0	67.8	11.3	18.0	[illegible]	[illegible]	78.4
[illegible]	[illegible]	22.7	[illegible]	89.3	[illegible]	114.0	120.0	112.0	103.0	[illegible]	[illegible]	[illegible]	[illegible]	104.5
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	121.0	123.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	51.8	73.2	106.0	125.0	124.0	127.0	136.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	116.1
[illegible]	12.1	36.4	[illegible]	[illegible]	123.0	[illegible]	[illegible]	105.0	79.1	[illegible]	[illegible]	[illegible]	[illegible]	98.3
[illegible]	[illegible]	[illegible]	[illegible]	124.0	155.0	146.0	121.0	[illegible]	93.4	[illegible]	21.4	[illegible]	[illegible]	116.7
[illegible]	[illegible]	[illegible]	[illegible]	136.0	121.0	124.0	124.0	95.9	49.4	10.3	10.3	11.5	818.0	[illegible]
[illegible]	[illegible]	19.3	61.3	[illegible]	108.0	129.0	97.8	117.0	[illegible]	13.3	16.8	10.8	761.7	[illegible]
[illegible]	5.7	34.7	[illegible]	[illegible]	128.0	127.0	137.0	122.0	86.3	33.1	17.4	13.2	882.1	102.6
[illegible]	[illegible]	33.9	71.3	123.0	89.8	125.0	130.0	119.0	90.4	26.8	[illegible]	6.4	835.1	97.1
[illegible]	[illegible]	[illegible]	[illegible]	121.0	97.8	117.0	102.0	78.7	[illegible]	6.8	4.8	5.8	700.9	81.5
[illegible]	.2	31.0	73.2	[illegible]	101.0	114.0	[illegible]	125.0	77.9	17.5	10.7	10.1	[illegible]	92.3
[illegible]	[illegible]	17.6	73.0	93.9	99.8	[illegible]	[illegible]	103.0	69.5	19.9	16.7	4.8	[illegible]	87.3
[illegible]	.3	26.0	64.1	113.0	105.0	[illegible]	[illegible]	132.0	87.1	12.9	18.9	12.5	[illegible]	96.7
[illegible]	[illegible]	32.1	71.8	111.0	108.0	101.0	[illegible]	133.0	90.0	17.8	13.9	[illegible]	[illegible]	96.1
[illegible]	[illegible]	[illegible]	71.3	108.0	102.0	[illegible]	[illegible]	134.0	[illegible]	.5	6.5	[illegible]	[illegible]	93.4
[illegible]	.4	[illegible]	[illegible]	[illegible]	78.5	[illegible]	[illegible]	117.0	45.9	[illegible]	5.9	5.8	[illegible]	74.0
Mean	8.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	81.6	[illegible]	21.5	[illegible]	[illegible]	100.0
[illegible]	[illegible]	4.21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13.28	9.49	[illegible]	[illegible]	[illegible]	[illegible]	

Records previous to October 1916 from U. S. Bureau of Reclamation.
Records from October 1916 to September 1934 as published by U. S. Geological Survey.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Bureau of Reclamation.

TABLE 188.—*Run-off of Rio Grande at El Paso, Tex.*

[illegible]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in per cent of mean
[illegible]	12.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16.9	32.9	[illegible]	[illegible]
[illegible]	27.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	40.7	[illegible]	[illegible]	20.3	21.2	1,927.0	[illegible]
[illegible]	[illegible]	[illegible]	46.2	187.0	436.0	175.0	41.1	.8	0	0	0	0	933.6	125.4
[illegible]	[illegible]	8.0	2.1	[illegible]	231.0	13.4	[2] 0	[2] 0	[illegible]	[illegible]	[2] 0	[illegible]	319.8	43.0
[illegible]	[illegible]	.3	15.0	72.0	127.0	19.0	10.0	0	1.0	37.0	0	6.0	200.0	38.9
[illegible]	[illegible]	[3] 34.0	[illegible]	[3] 210.0	[3] 150.0	[3] 205.0	[illegible]	[3] 131.0	[3] 5.0	[3] 15.0	[3] 16.0	[3] 29.0	1,077.0	144.7
[illegible]	27.0	21.0	17.0	127.0	75.0	5.0	23.0	5.0	2.0	30.0	[illegible]	30.0	[illegible]	49.7
[illegible]	18.7	10.8	[illegible]	104.0	511.0	363.0	81.8	[illegible]	41.9	108.0	[illegible]	41.8	1,360.9	182.9
[illegible]	30.1	33.7	20.0	97.9	140.0	112.0	[illegible]	31.2	2.3	.2	[illegible]	[illegible]	[illegible]	89.9
[illegible]	12.9	11.3	7.1	8.8	10.3	0	19.6	.4	0	.1	[illegible]	2.8	73.4	9.9
[illegible]	8.1	5.7	.5	.3	44.8	93.1	.1	0	16.5	[illegible]	[illegible]	.7	169.8	[illegible]
[illegible]	.3	4.5	3.7	0	158.0	77.0	12.6	60.7	21.0	[illegible]	12.8	[illegible]	363.9	[illegible]
[illegible]	8.3	5.8	.6	7.9	.5	.3	[illegible]	11.5	9.3	1.4	.3	1.8	50.7	6.8
1903	.6	1.3	22.6	49.5	[illegible]	587.0	158.0	4.3	1.0	2.0	.3	2.4	1,033.0	138.8
[illegible]	1.0	.4	0	0	[illegible]	0	0	7.4	11.0	[illegible]	48.4	[illegible]	472.1	63.4
[illegible]	35.9	43.3	188.0	198.0	[illegible]	851.0	[illegible]	19.8	3.3	4.2	25.5	37.5	2,011.3	270.2
[illegible]	27.0	31.7	25.3	88.0	349.0	271.0	[illegible]	[illegible]	2.8	38.2	[illegible]	76.3	1,114.4	149.7
[illegible]	60.4	16.6	60.0	176.0	269.0	443.0	337.0	135.0	167.0	50.0	54.9	37.6	1,836.5	[illegible]
[illegible]	[illegible]	31.2	47.8	80.1	117.0	40.2	16.3	58.6	14.3	0	5.1	23.4	467.0	62.7
[illegible]	22.3	17.2	28.8	61.5	270.0	231.0	24.8	19.0	118.0	[illegible]	20.3	22.8	874.0	117.4
[illegible]	[illegible]	16.7	92.9	117.0	274.0	33.1	.1	0	.1	0	0	[illegible]	[illegible]	[illegible]
[illegible]	9.3	11.9	43.5	[illegible]	248.0	229.0	[illegible]	73.6	11.6	294.0	119.0	62.4	[illegible]	[illegible]
1912	18.6	32.3	60.4	96.0	382.0	511.0	[illegible]	30.8	20.3	1.2	[illegible]	27.0	[illegible]	182.3
[illegible]	18.8	35.0	15.6	[illegible]	88.6	43.0	5.7	0	0	6.7	17.1	21.1	[illegible]	[illegible]
[illegible]	21.9	23.2	[illegible]	[illegible]	[illegible]	[3] 185.0	[3] 180.0	70.1	[illegible]	[illegible]	51.0	67.5	[illegible]	[illegible]
1915	39.3	32.0	22.2	[illegible]	143.0	184.0	[illegible]	88.3	59.9	19.5	1.9	[illegible]	[illegible]	[illegible]
[illegible]	3.4	16.3	36.5	53.8	93.8	112.0	53.7	[illegible]	25.9	39.9	.6	64.6	555.8	74.6
1917	64.8	65.7	58.8	[illegible]	73.3	76.2	111.0	81.1	77.9	[illegible]	43.8	[illegible]	887.8	[illegible]
1918	2.3	32.0	[illegible]	[illegible]	46.6	28.6	28.3	33.9	19.5	33.9	20.3	6.4	[illegible]	46.9
1919	3.5	17.1	42.9	[illegible]	90.2	71.1	67.2	62.0	50.9	[illegible]	16.5	7.3	[illegible]	[illegible]
[illegible]	[illegible]	13.1	49.5	70.4	[illegible]	82.6	84.1	107.0	74.8	79.7	28.2	41.1	707.2	95.0
[illegible]	[illegible]	24.8	67.0	[illegible]	76.6	93.6	105.0	114.0	[illegible]	100.0	69.2	43.9	[illegible]	116.9
[illegible]	17.8	47.9	67.5	[illegible]	74.9	79.0	[illegible]	112.0	82.3	[illegible]	36.7	37.8	[illegible]	104.6
[illegible]	[illegible]	33.7	47.2	72.2	87.3	90.3	[illegible]	123.0	60.4	51.6	23.3	32.3	[illegible]	97.9
[illegible]	[illegible]	[illegible]	[illegible]	91.0	122.0	[illegible]	111.0	107.0	77.4	32.0	21.1	27.7	810.2	[illegible]
[illegible]	[illegible]	[illegible]	56.7	75.1	73.2	68.4	[illegible]	96.9	87.4	25.3	15.3	14.9	633.8	85.1
[illegible]	[illegible]	[illegible]	41.3	65.4	69.4	[illegible]	[illegible]	63.1	65.0	21.1	21.0	[illegible]	556.8	74.8
[illegible]	[illegible]	24.6	[illegible]	59.0	71.7	73.8	86.8	90.7	80.6	30.3	[illegible]	20.6	619.6	[illegible]
[illegible]	12.7	26.6	[illegible]	80.3	[illegible]	[illegible]	86.1	[illegible]	67.2	31.7	22.3	14.3	624.0	83.8
[illegible]	[illegible]	[illegible]	37.1	62.5	70.7	56.2	83.0	107.0	[illegible]	[illegible]	14.3	12.7	552.1	[illegible]
[illegible]	[illegible]	[illegible]	42.9	62.5	[illegible]	67.8	82.4	83.0	51.9	25.8	16.7	16.1	532.4	71.5
[illegible]	[illegible]	14.9	40.5	[illegible]	53.7	63.1	[illegible]	88.6	52.5	26.7	22.2	14.1	517.6	69
[illegible]	[illegible]	16.9	34.5	57.2	[illegible]	[illegible]	[illegible]	85.7	67.4	34.9	24.4	[illegible]	[illegible]	[illegible]
[illegible]	11.8	24.9	39.6	[illegible]	64.5	79.1	[illegible]	[illegible]	66.7	33.6	[illegible]	[illegible]	[illegible]	81.8
[illegible]	11.2	33.1	43.5	56.7	[illegible]	[illegible]	73.8	[illegible]	[illegible]	[illegible]	11.4	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	61.8
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

[illegible]

TABLE 189.—*Run-off of Rio Grande at Tornillo Bridge, Tex.*

[Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1927										12.2	[illegible]	[illegible]	
1928	8.2	10.4	8.1	28.0	26.7	13.6	22.1	[illegible]	27.6	13.9	16.8	10.7	215.3
1929	8.2	3.5	4.7	10.2	25.5	5.1	21.3	59.6	10.3	12.7	[illegible]	7.4	178.1
1930	[illegible]	4.4	9.2	10.1	9.8	[illegible]	24.5	2.75	[illegible]	10.3	7.7	11.1	[illegible]
1931	8.3	6.8	8.9	20.1	12.2	8.7	[illegible]	40.8	17.8	[illegible]	12.4	9.5	176.2
1932	[illegible]	10.5	7.1	7.0	12.5	[illegible]	17.6	27.1	[illegible]	33.4	12.9	[illegible]	188.5
1933	[illegible]	12.2	[illegible]	[illegible]	11.8	[illegible]	24.5	28.1	[illegible]	17.4	9.3	14.3	202.8
1934	10.1	20.4	[illegible]	3.5	6.1	2.6	9.2	7.0	8.0	6.7	[illegible]	4.0	[illegible]
1935	[illegible]	2.4	.5	.6	.6	[illegible]	1.6	21.7	[illegible]	7.0	[illegible]	[illegible]	99.7

Records from October 1927 to December 1930 from reports of U. S. Geological Survey.
Records from January 1931 to December 1935 from water bulletins of the International Boundary Commission.

TABLE 190.—*Run-off of Rio Grande at Fort Quitman, Tex.*

[Drainage area 31,044 square miles.[1] Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1923										38.1	18.9	23.4	
1924	[illegible]	30.4	28.5	31.6	50.7	31.0	61.5	29.2	41.9	17.6	12.9	19.0	373.5
1925	13.8	15.8	18.3	13.5	14.7	18.7	8.9	58.1	59.5	20.8	13.2	12.6	[illegible]
1926	13.9	8.7	11.3	22.8	31.1	27.3	48.3	19.7	26.4	30.0	17.4	19.4	276.3
1927	13.5	14.1	7.7	11.3	13.5	19.5	14.0	45.3	42.2	21.2	20.2	18.4	240.9
1928	12.5	13.1	7.4	21.0	25.4	9.6	12.3	66.4	36.7	24.0	20.9	14.4	263.7
1929	10.6	8.7	9.2	7.6	22.0	7.1	14.4	62.1	15.6	21.4	17.1	13.0	211.8
1930	11.5	9.3	10.8	11.5	11.6	25.5	22.0	25.5	10.0	22.9	12.3	15.1	188.0
1931	9.4	10.2	10.1	34.7	21.7	8.8	17.2	36.6	17.6	11.3	16.5	14.6	211.7
1932	8.1	12.1	11.6	7.1	9.2	9.4	13.9	24.9	27.4	45.7	20.6	21.0	211.0
1933	12.8	15.6	12.2	12.6	10.8	29.0	20.5	19.1	28.9	22.0	13.0	17.3	213.8
1934	12.5	20.5	16.6	7.8	7.3	4.5	4.6	4.4	9.1	4.5	5.0	5.6	102.4
1935	5.4	3.5	1.1	1.2	[2] .9	3.6	4.3	24.3	57.2	20.7	10.5	12.7	145.4

[1] Exclusive of Closed Basin Area, San Luis Valley, Colorado.
[2] Partially estimated.

Records from October 1923 to December 1930 as published by U. S. Geological Survey.
Records from January 1931 to December 1935 from water bulletins of the International Boundary Commission.

TABLE 191.—*Run-off of Alamosa River near Monticello, N. Mex.*

[Drainage area 385 square miles. Unit, acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1929										[1] 133	[2] 551	[illegible]	
1930													
1931					435	506	660	1,750	878	746	549	491	
1932	466	543	523	457	578	530	636	653	560	527	522	509	6,504
1933	479	405	449	426	447	740	603	749	591	439	438	481	6,247
1934	479	400	430	492	945	418	415	1,070	430	448	433	468	6,428
1935	378	366	412	408	458	415	410	1,250	699	454	458	412	6,150

[1] Partially estimated.
[2] Estimated.

Records from October 1929 to December 1931 from reports of the New Mexico State engineer.
Records from January 1932 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 192.—*Run-off of Navajo River at Edith, Colo.*

[Drainage area 165 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1912										3.2	2.9	2.6	
1913	[2] 2.1	[2] 1.7	[2] 3.7	16.1	10.2	14.9	5.3	2.8	2.5	3.9	2.7	2.6	68.5
1914	[2] 2.5	[2] 1.9	9.9	20.7	32.8	[illegible]				8.7	3.7	[2] 2.5	
1915	[2] 2.2	[2] 2.7	6.8	25.2	34.7	38.4	20.7	6.2	3.1	2.6	2.4	[2] 2.4	147.4
1916	2.5	3.8	21.2	32.2	36.3	33.4	20.2	12.8	4.6	12.1	3.3	3.2	185.6
1917	3.8	2.8	3.2	20.5	32.2	54.5	([1])	([1])	3.4	2.8	2.0	2.3	
1918	1.9	2.2	5.3	9.3	18.7	21.8	8.5	4.4	3.3	2.2	1.9	2.0	81.5
1919	2.3	2.9	8.7	22.5	45.3	24.1	17.0	6.9	4.6	4.8	4.8	4.8	148.7
1920	2.9	4.0	21.8	42.1	78.3	46.5	17.8	9.3	3.4	2.7	2.7	2.6	231.1
1921	2.2	1.9	4.2	9.7	32.2	46.5	15.2	14.4	5.3	3.6	2.6	2.7	140.5
1922	2.4	3.1	7.2	26.6	56.5	35.7	9.4	3.5	2.1	1.9	2.0	2.0	152.4
1923	3.3	4.5	6.3	14.2	33.2	29.2	11.2	7.9	6.3	5.7	3.3	2.9	128.0
1924	3.5	3.8	4.3	26.3	23.4	20.1	13.0	4.2	2.3	1.9	1.8	1.7	106.3
1925	1.1	2.6	7.9	19.5	23.0	17.6	8.5	5.3	4.7	7.0	3.2	2.8	103.2
1926	[3] 2.8	[3] 3.0	[3] 6.5	22.3	34.2	30.6	14.8	5.0	2.5	2.8	[3] 2.1	[3] 2.2	128.8
1927	[3] 2.3	[3] 2.8	6.3	27.0	40.5	24.4	15.7	6.5	16.8	6.5	5.7	[3] 3.9	158.4
1928	[2] 3.4	[2] 3.7	[2] 6.7	9.4	27.4	13.5	5.4	3.8	1.6	1.5	[3] 2.1	[2] 1.8	80.3
1935						51.0	21.4	8.7	5.8	4.5	[3] 2.6	[3] 2.0	

[1] Partial record.
[2] Estimated.
[3] Partially estimated.

Records previous to October 1913 as published by U. S. Geological Survey in Water Supply Paper No. 358.
Records from October 1913 to December 1928 from reports of the New Mexico State engineer.
Records from June to December 1935 are provisional records furnished by U. S. Geological Survey.

PART I

APPENDIX B.—ESTIMATES OF WATER PRODUCTION IN THE UPPER RIO GRANDE BASIN, 1890-1935

Drainage Areas

Since the run-off from many tributary drainages has never been measured it was required to estimate their run-off by comparison with that of drainages which have been measured. One of the first requirements for estimating was therefore a detailed compilation of the drainage areas for all streams. Detail topographic maps are available for only a very limited portion of the upper Rio Grande drainage and the determination of drainage areas was required to be based in the main on general maps of the Geological Survey, Forest Service, and State agencies. Using these maps, the various drainages were measured by planimeter and the results are given in table 193. In this table the drainage areas are arranged as nearly as possible in consecutive downstream cumulative order with subtotals at gaging stations and at the confluence of tributaries with the main stream.

Water Production, San Luis Section, Colorado

In accordance with natural divisions of this section, the estimates of water production were segregated to the closed basin, the southwest and the southeast areas and the production derived is the run-off from the mountainous regions at the rim of the valley floor or approximately at the 8,500-foot contour. No account is taken of production due to precipitation on the floor of the valley. Although this is a factor in the total water production it is very small in proportion to the mountain run-off production. Of the three areas, the southwest is the most important with respect to contribution of water to the Rio Grande. Knowledge of water production in the closed basin becomes of importance in investigations looking to drainage of this basin to the Rio Grande. The production of the southeast area has for many years and is at present practically all used in irrigation so that its contribution to the Rio Grande is very small.

TABLE 193.—*Drainage areas in upper Rio Grande Basin*

SAN LUIS SECTION, COLORADO

Closed basin	Drainage area, square miles	
Kerber Creek near Villa Grove (gage)	[illegible]	
San Luis Creek near Villa Grove (gage)		[illegible]
Villa Grove to Isabel Creek, inclusive:		
Above foothill line—Group A	[illegible]	
Foothill line to San Luis Creek	112. 4	
		[illegible]
Crestone Creek to Deadman Creek inclusive:		
Above foothill line—Group B	42. 6	
Foothill line to San Luis Creek	130. 0	
		172. 6
Villa Grove to Saguache Creek—West side		100. 0
Saguache Creek near Saguache (gage)	490. 0	
Gage to San Luis Creek	396. 0	
Saguache Creek		886. 0
Carnero Creek near La Garita (gage)	117. 0	
La Garita Creek near La Garita (gage)	61. 0	
Carnero and La Garita gages to San Luis Creek	162. 0	
Carnero and La Garita Creeks		340. 0
San Luis Creek above sump		1, 968. 0
Pole, Sand, Medano and Zapato Creeks to southern boundary closed basin:		
Above foothill line—Group C	102. 0	
Foothill line to sump	362. 0	
		464. 0
Direct to sump—west side		508. 0
Sump		972. 0
Closed basin		2, 940
Del Norte		
Rio Grande at Forty Mile Bridge (gage)		163
Direct—left bank to Clear Creek		36. 5
Clear Creek below Continental Reservoir gage	[illegible]	
Clear Creek		141. 0
Direct—left bank to Wason		135. 0
Direct—right bank to Wason		224. 5
Rio Grande at Wason (gage)		700
Direct—right bank to Goose Creek		13. 0
Goose Creek		87. 0
Direct—right bank to South Fork		28. 0
South Fork Rio Grande near South Fork (gage)		216. 0
Direct—right bank to Del Norte gage		46. 0
Direct—Left bank to Embargo Creek		162. 0
Embargo Creek		62. 4
Direct—left bank to Del Norte gage		5. 6
Rio Grande near Del Norte (gage)		1, 320
Direct—left bank to Monte Vista gage		103. 5
Direct—right bank to Pinos Creek		18. 1
Pinos Creek near Del Norte gage	62. 0	
Pinos Creek		94. 0

TABLE 193.—*Drainage areas in upper Rio Grande Basin*—Cont'd

SAN LUIS SECTION, COLORADO—Continued

Live area—Continued		Drainage area, Sq. mi.
Direct—right bank to San Francisco Creek		11. 1
San Francisco Creek		21. 0
Direct—right bank to Monte Vista gage		19. 0
Rio Grande near Monte Vista (gage)		1, 590
Direct—left bank to Alamosa		38. 6
Raton Creek near Monte Vista	13. 0	
Raton Creek and direct—right bank to Alamosa		83. 4
Rio Grande at Alamosa (gage)		1, 712
Dry Creek near Monte Vista	6. 6	
Rock Creek near Monte Vista (gage)	38. 0	
Gato Creek at Tipton's Ranch (gage)	31. 5	
Dry, Rock and Gato Creeks and direct right bank to Alamosa Creek		457. 7
Alamosa Creek below Terrace Reservoir (gage)	120. 0	
Alamosa Creek		190. 0
Direct—right bank to La Jara Creek		6. 0
La Jara Creek near Capulin (gage)	73. 0	
La Jara Creek		240. 0
Direct—left bank to Trinchera Creek		193. 4
Trinchera Creek above Mountain Home Reservoir (gage)	61. 0	
Direct to Sangre de Cristo Creek	97. 4	
Sangre de Cristo Creek near Fort Garland (gage)	176. 0	
Direct to Mouth	6. 0	
Ute Creek near Fort Garland (gage)	32. 0	
Direct to mouth	8. 6	
Cottonwood Creek	15. 0	
Sangre de Cristo Creek	237. 6	
Direct to mouth	20. 6	
Trinchera Creek		416. 6
Direct—right bank to Conjeos River		59. 3
Conejos River near Mogote (gage)	282. 0	
Direct—left bank to mouth	153. 5	
Direct—right bank to Manassa	86. 0	
Los Pinos River near Ortiz (gage)	[1] 167. 0	
San Antonio River at Ortiz (gage)	[1] 110. 0	
Direct to mouth (Manassa)	[1] 71. 0	
San Antonio River	348. 0	
Direct—right bank to mouth	17. 5	
Conejos River		887. 0
Direct—left bank to Culebra Creek		186. 3
Culebra Creek at San Luis (gage)	220. 0	
Rito Seco	53. 7	
Direct to mouth	59. 0	
Culebra Creek		332. 7
Direct—left bank to Lobatos (gage)		70. 0
Direct—right bank to Lobatos (gage)		49. 0
Rio Grande near Lobatos (gage)		4, 800
Direct—right bank to Colorado-New Mexico line		84. 4
Direct—left bank to Costilla River		65. 6
Costilla River in Colorado (included in New Mexico figure)	0. 0	
Rio Grande at Colorado-New Mexico State line		4, [illegible]

MIDDLE SECTION, NEW MEXICO

Costilla River (includes Colorado area)		287. 0
Direct—left bank, to Latir Creek		[illegible]
Latir Creek		22. 5
Direct—left bank to Rio Colorado		[illegible]
Rio Colorado near Questa (gage)	112. 0	
Direct to mouth	77. 0	
Rio Colorado (Red River)		189. 0
Direct—left bank to Rio Hondo		36. 0
Rio Hondo at Valdez (gage)	38. 0	
Direct to Arroyo Hondo (gage)	33. 0	
Rio Hondo		71. 0
Direct—left bank to Rio Taos		37. 5
Rio Lucero near Arroyo Seco (gage)	17. 0	
Rio Taos at Los Cordovas (gage)	359. 0	
Direct to mouth	37. 0	
Rio Taos		396. 0
Direct—right bank to Taos Junction Bridge		376. 0
Rio Grande below Taos Junction Bridge (gage)		6, 550
Direct—left bank to Embudo Creek		55. 0
Embudo Creek at Dixon (gage)	305. 0	
Direct to mouth	1. 0	
Embudo Creek		306. 0
Direct—right bank to Arroyo Aguaje de Petaca		136. 5
Arroyo Aguaje de Petaca		223. 0
Direct—Right bank to Embudo		56. 5
Rio Grande at Embudo (gage)		7, 327
Direct—left bank to Truchas River		6. 4
Truchas River		63. 0
Direct—left bank to Rio Santa Cruz		74. 6
Direct—right bank to Rio Chama		25. 0
Rio Chama at Parkview (gage)	[3] 405. 0	
Nutritas Creek near Tierra Amarilla (gage)	51. 5	
Direct to mouth	12. 5	
Nutrias Creek	64. 0	
Willow and Horse Lake Creeks	211. 5	
Burford and Rock Lake Creeks	166. 5	
Direct—left bank to El Vado Dam	26. 0	
Rio Chama below El Vado Dam (gage)	873. 0	
Direct—left bank to Nutrias Creek	14. 3	
Nutrias Creek near Cebolla (gage)	22. 0	
Direct to mouth	81. 1	

[1] 17 square miles of Los Pinos and 128 of San Antonio River drainage area [illegible] in New Mexico.

[3] [illegible] Includes 204 square miles in Colorado.

TABLE 193.—*Drainage areas in upper Rio Grande Basin*—Contd.

MIDDLE SECTION, NEW MEXICO—Continued

		Drainage Areas, Square Miles	
Nutrias Creek		103.1	
Direct—left bank to Cebolla Creek		14.8	
Cebolla Creek		128.0	
Direct—left bank to Arroyo Seco		14.3	
Direct—right bank to Rio Gallina		70.0	
Rio Gallina		522.0	
Direct—right bank to Ojitos Canyon		12.5	
Ojitos Canyon		20.0	
Direct—right bank to Rio Puerco		28.2	
Rio Puerco		216.0	
Direct—right bank to Canones Creek		12.3	
Canones Creek		95.0	
Arroyo Seco (Horn River) near Canjilon (gage)	16.0		
Direct to mouth	156.0		
Arroyo Seco		172.0	
Direct—left bank to El Rito Creek		135.5	
El Rito Creek near El Rito (gage)	52.0		
Direct to mouth	69.0		
El Rito Creek		121.0	
Direct—right bank to Abiquiu Creek		31.4	
Abiquiu Creek		40.0	
Direct—right bank to Bear Creek		56.5	
Bear Creek		47.4	
Direct—left bank to Rio Ojo Caliente		34.5	
Rio Vallecitos at Vallecitos (gage)	111.5		
Rio Ojo Caliente at La Madera (gage)	344.0		
Direct to mouth	171.0		
Rio Ojo Caliente		515.0	
Direct—left bank to Chamita		75.0	
Direct—right bank to Chamita		20.2	
Rio Chama near Chamita (gage)		3,202.0	
Rio Chama			3,202.0
Direct—right bank to Otowi Bridge			181.0
Rio Santa Cruz at Cundiyo (gage)		85.7	
Direct to mouth		102.8	
Rio Santa Cruz			188.5
Direct—left bank to Pojoaque Creek			43.7
Nambe Creek near Nambe (gage)		37.0	
Pojoaque Creek			185.0
Direct—left bank to Otowi Bridge			6.8
Rio Grande at Otowi Bridge (gage)			11,303
Direct to Cochiti			358.0
Rio Grande at Cochiti (gage)			11,661
Direct—left bank to Santa Fe Creek			11.2
Santa Fe Creek near Santa Fe (gage)		22.0	
Arroyo Hondo near Santa Fe (gage)		14.0	
Direct—below Santa Fe and Arroyo Hondo gages		192.0	
Santa Fe Creek			228.0
Direct—left bank to Galisteo Creek			[illegible]
Galisteo Creek			[illegible]
Direct—left bank to San Felipe			[illegible]
Direct—right bank to San Felipe			[illegible]
Rio Grande at San Felipe (gage)			13,086
Direct—left bank to Tijeras Arroyo			305.0
Tijeras Arroyo			144.6
Direct—right bank to Jemez Creek			54.3
Jemez Creek near San Ysidro (gage)		854.0	
Direct to mouth		155.0	
Jemez Creek at mouth near Bernalillo (gage)			1,009.0
Direct—right bank to Isleta			371.0
Direct—left bank to Isleta			32.1
Rio Grande at Isleta (gage)			15,002
Direct—right bank to Rio Puerco			511.0
Bluewater Creek near Bluewater (gage)	235.0		
Rio Puerco at Rio Puerco (gage)	4,795.0		
Direct to mouth	242.0		
Rio Puerco			5,037.0
Direct—right bank to Rio Salado			77.0
Rio Salado			1,434.0
Direct—right bank to San Acacia			5.0
Direct—left bank to San Acacia			1,131.0
Rio Grande at San Acacia (gage)			23,197
Direct—left bank to San Marcial			363.0
Direct—right bank to San Marcial			616.0
Rio Grande at San Marcial (gage)			24,176

ELEPHANT BUTTE-FORT QUITMAN SECTION, NEW MEXICO AND TEXAS

Direct—left bank to Elephant Butte Dam		140.7
Direct—right bank to Alamosa River		[illegible]
Alamosa River near Monticello (gage)	385.0	
Direct to mouth	326.0	
Alamosa River		711.0
Direct—right bank to Rio Cuchillo		79.7
Rio Grande below Elephant Butte Dam (gage)		25,923
Rio Cuchillo		352.9
Direct—right bank to Palomas River		38.8
Palomas River		234.0
Direct—right bank to Percha Dam		549.0
Direct—left bank to Percha Dam		120.3
Rio Grande at Percha Dam (gage)		27,218
Direct—left bank to Leasburg Dam		225.0
Direct—right bank to Leasburg Dam		645.0
Rio Grande at Leasburg Dam (gage)		28,086
Direct—left bank to El Paso		842.0
Direct—right bank to El Paso		485.0
Rio Grande at El Paso (gage)		29,413
Direct to Fort Quitman in Texas		797.0
Direct to Fort Quitman in Mexico		834.0
Rio Grande at Fort Quitman (gage)		31,044

[illegible]

In the southwest area the Rio Grande is the principal stream and the main tributaries from north to south are Alamosa Creek, La Jara Creek, Conejos River, and San Antonio River. No tributaries of consequence enter the river from the north after it enters the valley floor. The estimates of water production for this area are based on the stream-flow records for Rio Grande near Del Norte, Pinos Creek near Del Norte, and Rock Creek near Monte Vista as a northern group, and Alamosa Creek below Terrace Reservoir, La Jara Creek near Capulin, Conejos River near Mogote, Los Pinos River near Ortiz, and San Antonio River at Ortiz as a southern group. The Rio Grande record begins with July 1889, that for the Conejos River with May 1903, and the others at later dates and covering considerably shorter periods. As the principal basis for the estimates, the monthly record for Rio Grande near Del Norte was completed for the period 1890–1935 by supplying missing months from curves of monthly run-off relations to other Rio Grande stations or from mean monthly distribution relations. The record was then corrected for regulation above the station by storage and the diversions of Del Norte Irrigation District to give natural flow or the flow which would have occurred at the station without any upstream regulation. There is a small amount of irrigation in the mountain valleys above the station which was neglected in deriving the natural-flow figures. Similarly, the monthly record for Conejos River near Mogote was extended and missing months estimated to cover the 1890–1935 period. As there is no storage on the Conejos this record was taken to represent the natural flow. Corrections to the Alamosa and La Jara Creek records were made for storage regulation on those streams.

TABLE 194.—*Mountain run-off to southwest area, San Luis Valley*

[Estimated natural run-off at rim of valley. Drainage area 2,392 square miles. Unit, 1,000 acre-feet]

Year and month	Northern group: Rio Grande near Del Norte, 1,320 square miles	Northern group: Unmeasured, 189 square miles	Southern group: Conejos River near Mogote, 282 square miles	Southern group: Unmeasured, 601 square miles	Total
1890					
January	13.5	1.1	2.4	2.4	19.4
February	11.1	1.1	2.1	2.0	16.3
March	27.5	2.8	6.2	9.0	45.5
April	54.4	8.0	23.0	38.0	123.4
May	266.2	25.0	110.0	145.0	546.2
June	227.0	17.0	93.0	59.0	396.0
July	92.9	6.0	35.0	21.0	154.9
August	37.5	2.6	11.0	7.5	58.6
September	22.8	1.3	5.0	4.0	33.1
October	28.9	1.6	6.0	4.8	41.3
November	20.2	1.2	4.3	3.3	29.0
December	18.4	1.2	3.5	3.0	26.1
Year	820.4	68.9	301.5	299.0	1,489.8
1891					
January	16.9	1.5	3.0	2.9	24.3
February	13.9	1.2	2.6	3.0	20.7
March	26.8	2.7	6.1	9.0	44.6
April	84.0	17.0	35.0	59.0	195.0
May	202.2	13.0	84.0	108.0	407.2
June	247.0	20.0	101.0	65.0	433.0
July	103.7	7.0	39.0	23.0	172.7
August	40.7	2.7	12.0	8.0	63.4
September	31.4	1.9	7.5	5.2	46.0
October	51.9	3.0	13.0	9.0	76.9
November	22.3	1.4	4.6	3.8	32.1
December	19.1	1.2	3.7	3.4	27.4
Year	859.9	72.6	311.5	299.3	1,543.3
1892					
January	16.9	1.5	3.0	2.9	24.3
February	14.4	1.3	2.7	3.1	21.5
March	19.5	1.7	4.8	6.0	32.0
April	62.4	10.0	26.0	43.0	141.4
May	160.2	7.0	66.0	82.0	315.2
June	130.0	7.0	55.0	33.0	225.0
July	45.2	2.5	16.0	9.0	72.7
August	27.2	2.0	9.0	6.3	44.5
September	15.6	.7	2.8	2.8	21.9
October	15.9	1.0	2.7	2.5	22.1
November	14.3	1.0	3.4	2.9	21.6
December	10.8	.7	2.0	2.1	15.6
Year	532.4	36.4	193.4	195.6	957.8
1893					
January	9.8	.9	1.7	2.0	14.4
February	9.7	.9	1.8	2.0	14.4
March	15.5	1.4	4.1	5.3	26.3
April	31.8	2.5	13.0	21.0	68.3
May	120.2	6.0	50.0	59.0	235.2
June	104.0	5.0	[illegible]	26.0	180.0
July	24.0	1.0	7.0	4.0	36.0
August	19.8	1.5	7.0	5.0	33.3
September	16.1	.8	3.0	3.0	22.9
October	16.2	1.0	2.8	2.6	22.6
November	14.3	1.0	3.4	2.9	21.6
December	10.8	.8	2.0	2.1	15.7
Year	392.2	22.8	140.8	134.9	690.7
1894					
January	10.8	.9	1.9	2.0	15.6
February	9.7	.9	1.8	2.0	14.4
March	18.5	1.7	4.6	6.0	30.8
April	55.0	8.0	23.0	38.0	124.0
May	147.2	8.0	61.0	75.0	291.2
June	63.7	3.0	29.0	15.0	110.7
July	22.1	1.0	6.5	4.0	33.6
August	23.5	1.8	8.0	5.7	39.0
September	21.1	1.2	4.2	3.6	30.1
October	22.1	1.4	4.5	3.8	31.8
November	16.8	1.1	3.8	3.1	24.8
December	13.8	.9	2.6	2.6	19.9
Year	424.3	29.9	150.9	160.8	765.9
1895					
January	12.3	1.0	2.2	2.1	17.6
February	10.6	1.0	2.0	2.0	15.6
March	26.8	2.7	6.1	9.0	44.6
April	119.1	24.0	50.0	85.0	278.1
May	141.1	8.0	58.0	71.0	278.2
June	139.0	8.0	59.0	36.0	242.0
July	64.3	4.0	23.0	14.0	105.3
August	45.1	3.1	13.0	9.0	70.2
September	26.7	1.6	6.0	4.5	38.8
October	25.8	1.5	5.9	4.7	37.9
November	20.4	1.2	4.4	3.4	29.4
December	18.5	1.2	3.6	3.3	26.6
Year	649.8	57.3	233.2	244.0	[illegible]
1896					
January	17.0	1.5	3.0	3.0	[illegible]
February	15.6	1.5	2.9	3.0	[illegible]
March	30.8	3.5	6.8	10.0	51.1
April	91.1	19.0	38.0	64.0	212.1
May	151.5	9.0	63.0	78.0	[illegible]
June	51.5	2.6	25.0	13.0	92.1
July	23.8	1.0	7.0	4.2	36.0
August	16.2	1.3	6.0	4.5	28.0
September	29.7	1.8	7.0	5.0	43.5
October	27.9	1.6	6.0	4.9	40.4
November	18.1	1.2	[illegible]	3.1	26.4
December	13.9	1.0	2.6	2.6	20.1
Year	[illegible]	[illegible]	171.3	195.3	[illegible]

TABLE 194.—*Mountain run-off to southwest area, San Luis Valley*—Continued

Year and month	[illegible] Norte, 1,320 [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	1.2	[illegible]	2.5	20.1
[illegible]	[illegible]	1.1	[illegible]	2.1	16.5
[illegible]	[illegible]	[illegible]	[illegible]	9.0	45.1
[illegible]	[illegible]	11.0	27.0	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	117.0	[illegible]
[illegible]	[illegible]	14.0	[illegible]	52.0	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	9.0	6.0	46.0
[illegible]	[illegible]	2.3	[illegible]	6.0	[illegible]
[illegible]	[illegible]	[illegible]	25.0	17.0	[illegible]
[illegible]	[illegible]	2.3	7.0	[illegible]	[illegible]
[illegible]	[illegible]	1.5	4.8	4.0	[illegible]
[illegible]	[illegible]	[illegible]	200.6	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	22.0	17.0	80.0	[illegible]
[illegible]	[illegible]	10.0	[illegible]	88.0	335.5
June	[illegible]	21.0	[illegible]	68.0	[illegible]
[illegible]	[illegible]	7.0	[illegible]	23.0	168.5
[illegible]	[illegible]	2.2	[illegible]	7.0	[illegible]
[illegible]	[illegible]	1.0	4.0	[illegible]	27.5
[illegible]	[illegible]	[illegible]	2.8	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1.2	2.9	20.1
[illegible]	[illegible]	[illegible]	2.0	2.0	16.0
[illegible]	[illegible]	[illegible]	206.[illegible]	203.9	1,459.2
[illegible]	11.2	[illegible]	2.0	2.0	16.2
[illegible]	10.1	1.0	1.9	2.0	15.0
[illegible]	[illegible]	1.7	[illegible]	[illegible]	39.8
[illegible]	[illegible]	3.5	[illegible]	26.0	82.4
[illegible]	[illegible]	4.3	35.0	38.0	[illegible]
[illegible]	[illegible]	3.1	[illegible]	16.0	113.9
[illegible]	[illegible]	[illegible]	15.0	9.0	68.9
[illegible]	[illegible]	[illegible]	11.0	7.5	57.4
[illegible]	22.0	[illegible]	[illegible]	[illegible]	32.0
[illegible]	[illegible]	[illegible]	6.0	4.9	41.8
[illegible]	[illegible]	[illegible]	5.0	3.6	33.9
[illegible]	12.7	.8	2.3	2.3	18.1
[illegible]	[illegible]	[illegible]	133.6	121.3	672.9
[illegible]	9.3	.9	1.7	1.7	13.6
[illegible]	[illegible]	1.0	[illegible]	2.1	[illegible]
March	[illegible]	1.5	[illegible]	5.5	26.6
April	[illegible]	[illegible]	16.0	15.0	51.4
[illegible]	[illegible]	[illegible]	73.0	[illegible]	652.5
[illegible]	[illegible]	[illegible]	[illegible]	41.0	[illegible]
[illegible]	[illegible]	[illegible]	11.0	6.4	[illegible]
[illegible]	[illegible]	[illegible]	5.0	4.0	[illegible]
[illegible]	[illegible]	[illegible]	2.7	2.9	21.5
October	[illegible]	[illegible]	[illegible]	3.6	[illegible]
[illegible]	[illegible]	1.0	[illegible]	3.0	22.4
[illegible]	12.4	.9	[illegible]	2.2	17.7
Year	[illegible]	[illegible]	[illegible]	189.4	991.6
[illegible]	[illegible]	[illegible]	2.2	[illegible]	18.0
[illegible]	[illegible]	.9	1.8	1.9	[illegible]
[illegible]	[illegible]	1.3	3.8	4.9	23.9
[illegible]	[illegible]	[illegible]	[illegible]	39.0	95.0
[illegible]	158.5	[illegible]	[illegible]	82.0	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	30.0	201.9
July	[illegible]	[illegible]	12.0	7.0	56.7
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	47.3
[illegible]	[illegible]	[illegible]	6.0	4.5	38.6
October	16.1	1.0	2.8	2.6	22.5
November	[illegible]	1.1	3.8	3.1	24.8
December	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Year	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
January	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
February	[illegible]	.8	1.6	1.8	[illegible]
[illegible]	[illegible]	1.3	3.9	[illegible]	24.4
[illegible]	78.1	[illegible]	16.0	[illegible]	83.9
May	72.4	1.6	[illegible]	[illegible]	[illegible]
[illegible]	76.7	1.8	18.0	[illegible]	[illegible]
[illegible]	8.9	.3	2.0	[illegible]	12.4
[illegible]	[illegible]	[illegible]	4.0	[illegible]	18.9
[illegible]	[illegible]	.6	2.0	2.5	17.4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
November	[illegible]	[illegible]	1.2	3.0	[illegible]
December	[illegible]	.8	[illegible]	[illegible]	[illegible]
Year	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Year and month	[illegible] group: Rio Grande [illegible] Norte, 1,320 [illegible] miles	[illegible] group: [illegible] miles	Southern group: Conejos River near [illegible] 282 square [illegible]	Southern group: [illegible] square miles	Total
January	3.6	[illegible]	[illegible]	1.1	5.7
[illegible]	[illegible]	[illegible]	[illegible]	1.8	9.0
[illegible]	10.1	1.0	3.7	2.8	17.6
[illegible]	44.6	5.0	18.0	[illegible]	96.6
[illegible]	[illegible]	11.0	79.4	101.0	[illegible]
June	[illegible]	[illegible]	138.0	90.0	[illegible]
July	[illegible]	[illegible]	39.7	24.0	172.2
[illegible]	[illegible]	[illegible]	[illegible]	7.0	[illegible]
[illegible]	[illegible]	[illegible]	9.3	6.0	47.8
[illegible]	[illegible]	1.3	[illegible]	[illegible]	37.8
[illegible]	[illegible]	[illegible]	3.0	2.8	24.0
[illegible]	[illegible]	[illegible]	[illegible]	1.9	15.3
Year	[illegible]	[illegible]	313.7	[illegible]	[illegible]
[illegible]	6.6	[illegible]	9	1.1	9.6
[illegible]	7.1	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	12.2	[illegible]	4.0	3.2	20.4
[illegible]	[illegible]	1.0	16.8	27.0	86.8
[illegible]	[illegible]	3.4	31.3	32.0	138.6
[illegible]	[illegible]	1.7	19.0	8.0	71.0
July	20.0	.8	[illegible]	3.0	28.5
[illegible]	42.1	2.9	19.4	13.0	77.4
September	41.2	2.5	13.9	8.0	65.6
[illegible]	89.1	[illegible]	32.7	21.0	146.6
November	21.0	1.3	3.7	3.0	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	2.6	19.4
Year	[illegible]	24.8	[illegible]	[illegible]	[illegible]
January	[illegible]	1.1	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	1.0	[illegible]	[illegible]	17.8
[illegible]	[illegible]	[illegible]	6.2	4.4	40.6
[illegible]	[illegible]	[illegible]	17.7	[illegible]	97.6
[illegible]	[illegible]	[illegible]	[illegible]	124.0	444.6
[illegible]	361.7	[illegible]	[illegible]	[illegible]	614.7
[illegible]	[illegible]	4.1	[illegible]	19.0	122.0
[illegible]	35.2	2.5	13.1	9.0	59.8
September	22.4	1.2	[illegible]	4.0	32.8
October	26.4	1.6	[illegible]	3.5	37.9
November	17.6	1.2	4.1	3.2	26.1
[illegible]	12.4	.9	2.3	[illegible]	17.9
Year	[illegible]	[illegible]	317	[illegible]	[illegible]
January	11.2	1.0	[illegible]	[illegible]	16.2
[illegible]	10.1	1.0	[illegible]	2.0	[illegible]
[illegible]	19.0	1.7	4.7	[illegible]	32.0
[illegible]	65.1	11.0	[illegible]	[illegible]	137.1
[illegible]	[illegible]	20.0	[illegible]	106.0	445.1
June	[illegible]	26.0	[illegible]	[illegible]	531.7
[illegible]	115.3	[illegible]	44.0	26.0	193.3
[illegible]	47.4	3.2	14.0	[illegible]	74.0
[illegible]	[illegible]	[illegible]	[illegible]	7.0	63.4
October	[illegible]	[illegible]	[illegible]	10.0	81.8
[illegible]	[illegible]	[illegible]	[illegible]	4.1	44.5
December	[illegible]	1.2	[illegible]	[illegible]	26.6
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	4.1	3.6	29.6
February	[illegible]	[illegible]	3.0	[illegible]	24.2
[illegible]	[illegible]	[illegible]	10.0	7.0	44.7
[illegible]	[illegible]	[illegible]	28.9	[illegible]	192.1
May	[illegible]	[illegible]	[illegible]	62.0	[illegible]
June	[illegible]	[illegible]	109.0	[illegible]	[illegible]
July	[illegible]	[illegible]	[illegible]	[illegible]	149.8
August	[illegible]	[illegible]	[illegible]	17.0	141.7
September	[illegible]	[illegible]	12.9	8.0	[illegible]
October	[illegible]	[illegible]	6.5	[illegible]	[illegible]
November	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
December	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Year	[illegible]	106.7	[illegible]	[illegible]	1,913.8
January	11.1	1.0	2.2	2.2	[illegible]
February	10.1	1.0	[illegible]	[illegible]	15.3
[illegible]	21.2	[illegible]	7.0	5.0	35.2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	83.7
[illegible]	[illegible]	[illegible]	31.7	17.0	[illegible]
[illegible]	[illegible]	[illegible]	69.6	43.0	[illegible]
[illegible]	[illegible]	[illegible]	26.6	[illegible]	111.7
[illegible]	[illegible]	[illegible]	17.7	[illegible]	[illegible]
September	20.5	1.2	7.0	[illegible]	33.7
[illegible]	16.7	1.1	6.3	[illegible]	20.1
[illegible]	[illegible]	.8	[illegible]	3.7	21.7
December	[illegible]	[illegible]	2.4	[illegible]	17.8
Year	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 194.—*Mountain run-off to southwest area, San Luis Valley*—Continued

Year and month	Northern group: Rio Grande near Del Norte, 1,320 square miles	Northern group: Unmeasured, 189 square miles	Southern group: Conejos River near Mogote, 282 square miles	Southern group: Alamosa Creek at Terrace Reservoir, 115 square miles	Southern group: Unmeasured, 486 square miles	Total
1909						
January	13.2	1.2	2.4	(1)	2.4	19.2
February	13.3	1.2	2.5	(1)	[illegible]	19.3
March	19.4	1.7	5.0	(1)	4.0	30.1
April	[illegible]	7.0	19.0	9.0	[illegible]	113.3
May	197.5	14.0	75.0	29.2	73.0	388.7
June	283.4	23.0	119.0	37.6	40.0	503.0
July	[illegible]	6.0	33.7	[illegible]	8.0	151.4
August	[illegible]	3.5	19.3	(1)	13.0	87.9
September	98.5	6.0	[illegible]	[illegible]	16.0	148.2
October	[illegible]	2.4	[illegible]	3.9	4.5	60.7
November	25.0	1.6	5.0	2.9	3.0	37.5
December	24.6	1.8	4.9	6.0	5.5	42.8
Year	909.4	69.4	322.8	[2] 99.8	200.7	1,602.1
1910						
January	19.9	1.8	3.6	(1)	3.3	28.6
February	16.6	1.5	2.8	(1)	2.5	23.4
March	40.1	5.0	10.4		7.0	62.5
April	83.6	17.0	29.9	11.4	40.0	181.9
May	211.5	17.0	75.0	29.0	73.0	405.5
June	143.4	8.0	43.9	18.9	15.0	229.2
July	37.0	2.2	10.9	5.8	3.6	59.5
August	29.3	2.2	10.5	[illegible]	3.5	52.1
September	19.5	1.2	3.8	1.7	1.6	27.8
October	22.3	1.4	3.9	(1)	3.4	31.0
November	18.3	1.2	3.5	(1)	3.0	26.0
December	13.6	1.0	3.7	(1)	3.3	21.6
Year	655.1	59.5	201.9	[2] 73.4	159.2	1,149.1

Year and month	Northern group: Rio Grande near Del Norte, 1,320 square miles	Northern group: Unmeasured, 189 square miles	Southern group: Conejos River near Mogote, 282 square miles	Southern group: Alamosa Creek at Terrace Reservoir, 115 square miles	Southern group: Unmeasured, 486 square miles	Total
1911						
January	15.5	1.4	3.4	(1)	3.0	23.3
February	13.6	1.3	2.5	(1)	2.3	19.7
March	21.2	2.0	5.0	(1)	4.0	32.2
April	57.3	9.0	21.6	7.2	30.0	125.1
May	205.9	15.0	85.5	[illegible]	81.0	416.0
June	286.2	[illegible]	123.0	40.7	[illegible]	515.9
July	170.9	12.0	70.1	21.4	15.0	289.4
August	59.4	4.1	20.5	7.4	5.5	96.9
September	39.3	2.8	17.1	7.2	5.0	71.4
October	151.0	8.0	[illegible]	18.4	19.0	242.4
November	32.5	1.8	6.0	(1)	4.2	44.5
December	25.3	1.6	[illegible]	(1)	4.1	36.0
Year	1,078.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1912						
January	21.2	1.9	4.7	(1)	4.0	31.8
February	16.1	1.5	3.1	3.1	5.5	29.3
March	17.7	1.6	5.6	[illegible]	10.0	38.3
April	34.8	3.0	13.2	4.1	19.0	74.1
May	230.9	20.0	114.0	33.6	107.0	505.5
June	259.0	20.0	103.0	33.4	35.0	450.4
July	106.7	8.0	38.6	21.8	10.0	185.1
August	48.8	3.7	[illegible]	10.5	4.0	76.5
September	26.1	2.2	3.8	3.2	2.0	37.3
October	23.7	1.5	5.0	(1)	4.0	34.2
November	16.1	1.0	5.1	(1)	3.8	26.0
December	11.3	.7	2.0	(1)	2.0	16.0
Year	812.4	65.1	307.6	[2] 113.1	[illegible]	[illegible]

Year and month	Northern group: Rio Grande near Del Norte, 1,320 square miles	Northern group: Unmeasured, 189 square miles	Southern group: Conejos River near Mogote, 282 square miles	Southern group: Unmeasured, 601 square miles	Total
1913					
January	10.5	1.0	2.6	2.5	16.6
February	9.5	1.0	2.4	2.2	15.1
March	16.0	1.5	3.4	2.6	23.5
April	48.5	6.0	8.9	13.0	76.4
May	147.1	8.0	56.0	8.0	279.1
June	124.0	6.0	48.7	29.0	207.7
July	67.9	4.3	12.1	7.0	91.3
August	40.2	2.8	4.1	3.0	50.1
September	28.7	1.7	3.9	3.5	37.8
October	35.1	2.0	7.4	5.5	50.0
November	23.4	1.4	3.2	2.8	30.8
December	24.0	1.5	4.8	4.0	34.3
Year	574.9	37.2	157.5	143.1	912.7

Year and month	Northern group: Rio Grande near Del Norte, 1,320 square miles	Northern group: Unmeasured, 189 square miles	Southern group: Conejos River near Mogote, 282 square miles	Southern group: Unmeasured, 601 square miles	Total
1914					
January	19.3	1.5	2.9	2.8	26.5
February	17.3	1.5	2.7	2.5	24.0
March	20.2	1.7	7.0	5.0	33.9
April	26.1	1.5	17.7	29.0	74.3
May	[illegible]	14.0	58.6	71.0	345.2
June	[illegible]	21.0	80.3	50.0	406.2
July	117.0	8.0	28.1	17.0	170.1
August	54.0	3.6	18.9	11.0	87.5
September	33.9	2.2	17.0	12.0	65.1
October	45.3	2.6	13.1	[illegible]	70.0
November	17.3	1.2	4.4	3.5	26.4
December	13.0	.9	2.5	2.5	18.9
Year	819.9	59.7	253.2	[illegible]	[illegible]

Year and month	Northern group: Rio Grande near Del Norte, 1,320 square miles	Northern group: Unmeasured, 189 square miles	Southern group: Conejos River, near Mogote, 282 square miles	Southern group: Alamosa Creek at Terrace Reservoir, 115 square miles	Southern group: La Jara Creek near Capulin, 73 square miles	Southern group: Los Pinos River near Ortiz, 167 square miles	Southern group: San Antonio River at Ortiz, 110 square miles	Southern group: Unmeasured, 136 square miles	Total
1915									
January	12.6	1.2	2.3	(1)		0.8		2.0	18.9
February	13.8	1.2	2.8	(1)		.9	[illegible]	1.4	20.1
March	17.8	1.5	3.7	(1)		1.5	[illegible]	1.3	26.0
April	46.2	5.7	18.4	6.1	2.6	14.0	4.5	3.8	101.3
May	125.2	7.0	35.4	17.6	3.3	30.5	5.0	4.3	238.3
June	216.6	14.0	92.8	34.9	2.0	28.6	1.5	3.1	393.5
July	91.9	6.0	43.0	14.5	1.8	6.3	.5	.7	164.7
August	36.8	2.7	12.9	4.9	.9	2.7	.6	0	61.5
September	28.1	1.9	6.0	2.5	.4	1.2	.3	[illegible]	40.4
October	22.3	1.5	5.0	1.9	.3	1.1	.3	0	32.4
November	[illegible]	1.2	3.6	(1)	(1)	1.2	(1)	[illegible]	26.8
December	12.7	.8	2.5	(1)	[illegible]	[illegible]		[illegible]	[illegible]
Year	643.0	41.7	238.4	[2] [illegible]	[2] 11.3	[illegible]	[illegible]	[illegible]	[illegible]

[1] Where no figure is given the run-off was not measured and its estimate has been included in the estimate for the unmeasured area.
[2] Partial year. Missing months are included in the total for the unmeasured area.

[illegible]

[illegible]	Northern group: [illegible] near Del Norte, 1,320 [illegible]	Northern group: [illegible] ured, 189 square miles	Southern group: Conejos [illegible] square [illegible]	Southern group: Alamosa Creek at Terrace Reservoir, 115 square [illegible]	Southern group: [illegible] Creek near Capulin, 73 square miles	Southern group: [illegible] River near Ortiz, [illegible]	Southern group: [illegible] at Ortiz, 110 square miles	Southern group: [illegible] ured, 136 [illegible]	[illegible]
[illegible]									
[illegible]	[illegible]	1.7	2.4	[illegible]	(1)	[illegible]	[illegible]	[illegible]	25.6
[illegible]	[illegible]	1.5	3.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	4.2	5.2	[illegible]	[illegible]	[illegible]	[illegible]	4.1	[illegible]
[illegible]	[illegible]	[illegible]	21.7	[illegible]	7.0	[illegible]	6.3	10.2	152.1
May	[illegible]	[illegible]	[illegible]	[illegible]	7.3	58.2	14.7	7.1	405.4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.2	37.4	[illegible]	1.8	474.3
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.3	[illegible]	7.7	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.6	3.3	.6	.1	138.6
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.7	1.8	.2	0	56.6
October	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.9	.1	119.2
November	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.0	50.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.0	28.2
Year	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36.9	1,724.2
[illegible]									
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
February	[illegible]	1.5	3.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27.0
[illegible]	[illegible]	1.8	5.0	1.2	[illegible]	[illegible]	[illegible]	[illegible]	34.4
[illegible]	[illegible]	4.3	19.4	5.3	5.7	[illegible]	[illegible]	25.0	102.6
[illegible]	125.1	7.0	46.4	18.8	9.2	32.5	9.3	12.4	[illegible]
[illegible]	373.5	36.0	138.0	68.0	3.2	45.7	[illegible]	5.0	671.9
July	195.5	14.0	76.2	28.5	0	12.1	1.2	0	327.5
August	50.5	3.6	15.4	7.3	0	2.0	.3	0	79.1
September	25.8	1.7	5.4	2.9	1.1	1.2	.7	0	38.8
[illegible]	[illegible]	[illegible]	3.1	1.3	1.1	.8	[illegible]	0	24.5
[illegible]	14.3	1.0	[illegible]	.8	.8	.8	.1	0	20.4
[illegible]	[illegible]	[illegible]	1.9	[illegible]	[illegible]	[illegible]	(1)	2.0	16.2
Year	[illegible]	[illegible]	[illegible]	[2] [illegible]	[2] [illegible]	[2] [illegible]	[2] 14.3	57.9	1,631.4
[illegible]									
[illegible]	[illegible]	1.0	1.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16.8
February	[illegible]	1.0	1.9	[illegible]	[illegible]	[illegible]	(1)	2.0	17.7
March	17.2	1.5	[illegible]	2.1	[illegible]	1.5	[illegible]	3.0	30.2
[illegible]	[illegible]	1.5	[illegible]	3.4	[illegible]	9.1	[illegible]	10.0	63.0
May	112.9	[illegible]	[illegible]	[illegible]	(1)	34.4	[illegible]	17.0	[illegible]
[illegible]	141.6	8.0	89.3	[illegible]	[illegible]	19.3	(1)	[illegible]	[illegible]
July	58.3	[illegible]	30.1	10.2	[illegible]	5.1	(1)	[illegible]	109.6
[illegible]	[illegible]	2.5	9.9	4.1	[illegible]	1.4	[illegible]	[illegible]	52.7
[illegible]	40.9	2.5	7.1	[illegible]	(1)	1.1	(1)	4.0	[illegible]
[illegible]	23.0	1.4	4.1	[illegible]	(1)	1.0	[illegible]	[illegible]	[illegible]
[illegible]	20.5	[illegible]	[illegible]	(1)	[illegible]	1.2	[illegible]	1.6	[illegible]
December	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20.1
Year	[illegible]	[illegible]	[illegible]	[2] 62.9	[illegible]	[2] [illegible]	[illegible]	[illegible]	963.8

[illegible]	Northern group: [illegible] Norte, [illegible]	Northern group: [illegible] Del Norte, 62 square miles	Northern group: [illegible] Creek near Monte Vista, 38 square [illegible]	Northern group: Unmeas-[illegible]	Southern group: Conejos [illegible] miles	Southern group: [illegible] Creek at Terrace [illegible]	Southern group: La Jara Creek near Capulin, 73 square miles	Southern group: [illegible] miles	Southern group: San Antonio River at Ortiz, 110 square miles	Southern group: [illegible] ured, 136 square [illegible]	Total
[illegible]											
January	[illegible]	[illegible]	[illegible]	1.4	2.7	(1)	[illegible]	(1)	[illegible]	[illegible]	22.1
February	[illegible]	[illegible]	[illegible]	[illegible]	2.8	[illegible]	[illegible]	(1)	[illegible]	3.0	[illegible]
March	21.6	[illegible]	[illegible]	1.8	5.2	(1)	(1)	[illegible]	[illegible]	7.4	36.0
[illegible]	[illegible]	1.0	2.5	4.7	29.5	9.3	6.1	21.5	3.7	8.9	[illegible]
[illegible]	[illegible]	8.4	4.5	6.3	84.2	34.1	6.9	53.1	[illegible]	[illegible]	460.2
June	[illegible]	[illegible]	2.6	3.0	[illegible]	[illegible]	6.0	17.0	[illegible]	9.2	312.9
July	107.8	1.1	2.0	[illegible]	31.4	12.4	[illegible]	7.8	[illegible]	[illegible]	174.4
[illegible]	54.1	1.7	1.0	1.0	10.8	[illegible]	.8	[illegible]	.3	[illegible]	[illegible]
September	28.7	1.0	.4	.4	5.8	2.0	.7	1.9	[illegible]	0	[illegible]
[illegible]	23.8	.7	.4	.3	4.4	1.0	.7	[illegible]	.4	0	33.0
[illegible]	[illegible]	.7	.5	.4	3.8	(1)	.8	[illegible]	(1)	[illegible]	28.7
[illegible]	[illegible]	[illegible]	[illegible]	1.2	[illegible]	[illegible]	(1)	[illegible]	(1)	3.5	26.9
[illegible]	[illegible]	[2] [illegible]	[illegible]	[illegible]	[illegible]	[2] [illegible]	[2] [illegible]	[illegible]	[2] 18.4	46.7	[illegible]

[illegible]

[2] Partial year. Missing months are included in the total for the unmeasured area.

TABLE 194.—*Mountain run-off to southwest area, San Luis Valley*—Continued

Year and month	Northern group				Southern group						Total
	Rio Grande near Del Norte, 1,320 square miles	Pinos Creek near Del Norte, [illegible] square miles	Rock Creek near Monte Vista, 38 square miles	Unmeasured, [illegible] square miles	Conejos River near Mogote, 282 square miles	Alamosa Creek at Terrace Reservoir, 115 square miles	La Jara Creek near Capulin, 73 square miles	Los Pinos River near Ortiz, [illegible] square miles	San Antonio River at Ortiz, 110 square miles	Unmeasured, [illegible] square miles	
1920											
January	18.1	(1)	(1)	1.5	3.3	(1)	(1)	(1)	(1)	3.1	26.0
February	16.7	(1)	(1)	1.5	3.1	(1)	(1)	(1)	(1)	3.9	25.2
March	19.2	(1)	.4	1.3	5.1	2.0		2.0	1.8	1.4	33.2
April	32.3	1.3	.8	1.5	9.4	11.5	1.4	8.5	12.4	2.0	81.1
May	270.9	14.0	5.7	9.7	115.0	38.4	10.8	76.8	34.0	14.5	589.2
June	374.2	20.2	4.7	9.2	188.0	55.5	3.4	45.8	5.0	5.3	711.3
July	140.6	[illegible]	1.8	2.7	67.0	23.7	3.7	9.5	.6	[illegible]	256.6
August	[illegible]	1.6	1.0	1.0	20.7	7.1	3.1	2.7	.8	.2	92.1
September	25.9	.7	.4	.3	6.4	2.7	1.0	.8	.4	0	38.6
October	25.0	.7	.4	.3	5.1	1.8	.9	.8	.5	0	35.5
November	22.2	(1)	(1)	1.4	3.9	(1)	.8	.9	(1)	1.5	30.7
December	16.4	(1)	(1)	1.1	3.2	(1)	(1)	(1)	(1)	3.0	23.7
Year	1,015.4	[2] 44.0	15.2	31.5	430.2	[2] 142.7	[2] 25.1	[2] 147.2	[2] 55.5	[illegible]	1,943.2
1921											
January	17.5	(1)	(1)	1.5	2.9	(1)	(1)	(1)	(1)	2.7	24.6
February	17.1	(1)	(1)	1.5	3.2	(1)	(1)	(1)	(1)	2.8	24.6
March	27.8	(1)	(1)	3.0	7.1	(1)	(1)	(1)	(1)	5.0	42.9
April	38.3	1.1	.5	1.2	10.9	(1)	(1)	(1)	(1)	7.0	59.0
May	209.6	6.5	1.8	3.6	63.3	(1)	4.9	(1)	(1)	48.0	337.7
June	378.5	8.1	2.0	3.7	106.0	(1)	1.3	(1)	(1)	67.0	566.6
July	138.3	3.4	.8	1.7	31.3	(1)	1.1	(1)	(1)	15.0	191.6
August	86.8	2.7	.8	1.2	19.3	(1)	.8	(1)	(1)	12.0	123.6
September	46.4	1.8	.4	.8	6.6	(1)	[illegible]	(1)	(1)	4.0	60.6
October	25.2	.8	.2	.2	3.9	(1)	.8	(1)	(1)	3.0	34.1
November	22.3	(1)	(1)	1.4	3.1	(1)	(1)	(1)	(1)	2.8	29.6
December	17.7	(1)	(1)	1.2	2.5	(1)	(1)	(1)	(1)	2.5	23.9
Year	1,025.5	[2] 24.4	[2] 6.5	21.0	260.1		[2] 9.5			171.8	1,518.8
1922											
January	19.0	(1)	(1)	1.7	3.5	(1)	(1)	(1)	(1)	3.1	27.3
February	18.3	(1)	(1)	1.6	3.5	(1)	(1)	(1)	(1)	4.6	28.0
March	22.9	(1)	(1)	2.0	5.5	(1)	(1)	(1)	(1)	8.0	38.4
April	46.8	1.7	.7	1.5	11.4	6.2	(1)	(1)	(1)	20.0	87.9
May	286.2	13.5	3.1	8.1	104.0	32.2	5.8	(1)	(1)	83.0	535.9
June	323.1	18.7	2.5	10.0	126.0	38.8	2.4	(1)	(1)	43.0	564.5
July	71.3	2.6	1.0	1.4	32.5	10.0	5.8	(1)	(1)	8.0	132.6
August	60.6	1.1	.8	.6	11.3	4.8	1.4	(1)	(1)	2.9	83.5
September	29.2	.6	.4	.3	3.5	3.2	.6	(1)	(1)	1.7	[illegible]
October	18.8	.7	.3	.3	2.9	1.2	(1)	(1)	(1)	1.8	26.0
November	16.2	(1)	(1)	1.2	3.7	1.3	(1)	(1)	(1)	2.0	24.4
December	16.1	(1)	(1)	1.3	3.4	1.5	(1)	(1)	(1)	2.5	24.8
Year	928.5	[2] 38.7	[2] 8.6	30.0	311.2	[2] 99.2	[2] 16.0			180.6	1,612.8
1923											
January	16.2	(1)	(1)	1.5	3.0	1.8	(1)	(1)	(1)	3.3	25.8
February	14.4	(1)	(1)	1.3	2.2	1.9	(1)	(1)	(1)	4.0	23.8
March	20.2	(1)	(1)	1.8	4.9	2.1	(1)	(1)	(1)	7.0	36.0
April	35.4	1.5	.5	1.4	22.0	4.1	(1)	(1)	(1)	28.0	92.9
May	211.1	8.4	2.8	5.5	121.0	32.7	8.9	(1)	(1)	89.0	479.4
June	251.8	8.2	2.0	3.7	127.0	31.1	1.8	(1)	(1)	40.0	465.6
July	93.3	2.9	1.3	1.7	42.2	15.0	5.1	(1)	(1)	10.0	171.5
August	63.4	2.3	.9	1.2	23.4	4.4	2.4	(1)	(1)	4.2	102.2
September	60.1	1.9	.9	1.0	19.7	6.0	1.7	(1)	(1)	5.5	96.8
October	54.2	1.6	.9	.3	17.5	3.3	1.4	(1)	(1)	4.5	83.7
November	34.9	.9	.5	.5	6.2	4.3	1.2	(1)	(1)	2.5	51.0
December	23.8	(1)	(1)	1.6	5.3	5.2	(1)	(1)	(1)	4.4	38.3
Year	878.8	[2] 27.7	[2] 9.8	21.5	394.4	109.9	[2] 22.5			202.4	1,667.0
1924											
January	19.9	(1)	(1)	1.7	4.4	(1)	(1)	(1)	(1)	3.8	29.8
February	17.5	(1)	(1)	1.5	3.7	(1)	(1)	(1)	(1)	3.0	25.7
March	19.3	(1)	(1)	1.7	4.9	(1)	(1)	(1)	(1)	3.4	29.3
April	72.8	4.9	2.7	5.6	34.0	7.8	(1)	(1)	(1)	41.0	168.8
May	241.7	12.9	3.8	8.2	108.0	35.9	4.6	(1)	(1)	87.0	502.1
June	219.1	7.7	1.8	4.7	81.5	24.8	2.7	(1)	(1)	51.0	393.3
July	59.0	1.8	.7	.9	27.2	6.4	4.8	(1)	(1)	6.0	106.8
August	26.2	.8	.3	.2	6.6	2.7	1.7	(1)	(1)	2.1	40.6
September	16.5	.5	.2	.3	3.2	1.4	1.0	(1)	(1)	1.4	24.5
October	18.9	(1)	(1)	1.2	3.9	.8	.9	1.3	.1	0	27.1
November	12.5	(1)	(1)	1.0	3.5	1.0	.7	1.8	.2	0	20.7
December	14.5	(1)	(1)	1.1	3.2	1.2	(1)	(1)	(1)	2.2	22.2
Year	737.9	[2] 28.6	[2] 9.5	28.1	284.1	[2] 82.0	[2] 16.4	[2] 3.1	[2] .3	200.9	1,390.9

[1] Where no figure is given the run-off was not measured and its estimate has been included in the estimate for the unmeasured area.
[2] Partial year. Missing months are included in the total for the unmeasured area.

Table 1[illegible].—[illegible] San Luis Valley—Continued

[illegible]	Northern group: Rio Grande near Del Norte, 1,320 square [illegible]	[illegible] square miles	[illegible] square miles	Alamosa Creek [illegible] Reservoir, 115 square [illegible]	Southern group: La Jara Creek, near [illegible] square miles	[illegible] River, near Ortiz, 167 square [illegible]	San Antonio River at Ortiz, [illegible]	Unmeasured 136 [illegible]	Total
[illegible]									
[illegible]	[illegible]	[illegible]	[illegible]					2.9	22.2
[illegible]	[illegible]	[illegible]	[illegible]					2.7	22.6
March	[illegible]	[illegible]	[illegible]		[illegible]			3.0	38.6
[illegible]	[illegible]	[illegible]	29.2	[illegible]	[illegible]	[illegible]	[illegible]	5.6	146.7
[illegible]	[illegible]	11.0	71.9	27.9	3.4	26.4	[illegible]	4.6	[illegible]
[illegible]	171.8	10.0	[illegible]	19.9	1.0	9.5	.6	1.6	269.1
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.9	3.1	.2	.4	118.4
[illegible]	45.2	[illegible]	14.9	5.4	2.0	[illegible]	.3	.1	75.6
[illegible]	[illegible]	[illegible]	8.5	3.5	.4	1.8	.1	0	74.3
October	54.6	[illegible]	11.2	3.1	.4	3.3	.1	[illegible]	[illegible]
November	24.6	1.6	[illegible]	2.1	[illegible]	1.8	.1	[illegible]	37.2
[illegible]	[illegible]	1.8	3.9	(1)	(1)	(1)	(1)	3.3	36.8
[illegible]	[illegible]	[illegible]	[illegible]	[2] 81.2	[2] 13.2	[2] 71.2	[2] 8.6	24.2	1,227.8
[illegible]									
[illegible]	19.9	1.7	3.8	(1)				3.2	28.6
[illegible]	15.5	1.4	3.1	(1)				2.7	22.7
March	17.7	1.6	4.4					3.2	[illegible]
[illegible]	36.2	3.5	18.9	4.3	2.9	[illegible]	8.2	4.2	94.2
[illegible]	160.7	10.0	76.9	23.1	6.7	46.1	14.4	9.0	[illegible]
[illegible]	195.2	1.4	92.8	27.3	2.0	22.4	.9	3.0	[illegible]
[illegible]	76.6	5.0	27.1	[illegible]	2.2	4.3	.2	.9	125.2
[illegible]	42.5	3.0	9.2	4.2	.6	1.7	[illegible]	[illegible]	61.4
[illegible]	20.9	1.4	2.7	1.5	.4	.9	[illegible]	[illegible]	[illegible]
[illegible]	20.4	1.3	3.8	.9	.4	[illegible]	[illegible]	[illegible]	27.9
[illegible]	16.9	1.1	3.0	.4	.3	1.1		[illegible]	[illegible]
[illegible]	17.0	1.2	3.0	.6	(1)	(1)		1.9	23.7
Year	[illegible]	32.6	248.7	[2] 71.2	[illegible]	[illegible]	[illegible]	[illegible]	1,153.4
[illegible]									
[illegible]	[illegible]	1.4	2.7	[illegible]				[illegible]	22.4
[illegible]	15.0	1.4	1.9	1.2				[illegible]	22.5
[illegible]	18.8	[illegible]	3.9	2.5				[illegible]	32.9
[illegible]	57.8	[illegible]	24.2	7.0	3.3	[illegible]		4.7	125.7
[illegible]	218.4	18.0	95.9	32.3	[illegible]	[illegible]	14.0	6.1	446.2
[illegible]	[illegible]	15.0	99.4	[illegible]	.9	[illegible]	[illegible]	1.4	[illegible]
July	139.1	[illegible]	[illegible]	14.5	1.2	7.0	[illegible]	.5	[illegible]
[illegible]	55.8	3.8	16.6	5.7	[illegible]	2.6	.2	0	[illegible]
[illegible]	146.2	[illegible]	28.8	8.3	1.2	6.0	.7	[illegible]	[illegible]
October	70.9	3.9	14.6	4.2	[illegible]	3.7	.4		98.7
[illegible]	[illegible]	2.0	[illegible]	3.3		[illegible]		[illegible]	48.1
[illegible]	22.0	1.3	[illegible]			1.1		[illegible]	31.3
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[2] 13.0	[2] 117.8	[illegible]	[illegible]	[illegible]
[illegible]									
[illegible]	19.9	[illegible]	[illegible]	[illegible]		.9		[illegible]	[illegible]
[illegible]	18.6	[illegible]	2.4	(1)					[illegible]
[illegible]	21.1	[illegible]	4.0	(1)		[illegible]		2.0	34.3
[illegible]	41.5	3.5	13.7	3.5	[illegible]	9.3	[illegible]	3.5	81.6
[illegible]	[illegible]	13.0	[illegible]	23.6	[illegible]	38.6	8.2	4.3	354.9
[illegible]	153.8	[illegible]	61.9	[illegible]	.5	13.2	[illegible]	.8	[illegible]
July	[illegible]	4.0	15.6	4.4	1.1	2.8	.3		95.1
[illegible]	32.8	2.4	8.6	4.0	.5	1.5	.4		50.2
September	23.0	1.5	4.9	[illegible]	[illegible]	1.0	.2	0	32.9
[illegible]	[illegible]	1.5	3.5	.9	[illegible]	.9	.1	[illegible]	30.6
[illegible]	21.8	1.4	3.0		.4	[illegible]		0	[illegible]
[illegible]	[illegible]	[illegible]	3.0	[illegible]		(1)		1.8	24.0
[illegible]	[illegible]	[illegible]	191.6	[illegible]	[illegible]	[2] 71.7	[illegible]	16.5	1,040.0
[illegible]									
January	16.6	[illegible]	2.8	0.7				2.5	24.1
[illegible]	14.6		2.7	.9				3.5	[illegible]
[illegible]	20.4	1.8	5.5	4.0			(1)	10.0	41.7
[illegible]	53.1	6.0	23.3	9.3	4.1	[illegible]	10.0	[illegible]	129.7
[illegible]	222.6	19.0	110.0	32.8	5.9	48.4	12.5	7.9	[illegible]
[illegible]	248.1	18.0	[illegible]	29.5	1.5	17.0	.8	[illegible]	414.5
July	94.9	6.0	[illegible]	[illegible]	1.0	4.7	.6	.4	[illegible]
[illegible]	[illegible]	7.0	[illegible]	11.7	.3	[illegible]			[illegible]
[illegible]	[illegible]	6.0	27.1	9.1	[illegible]	[illegible]		0	133.7
October	59.8	3.3	10.1	3.1	.6	[illegible]	[illegible]	.1	[illegible]
[illegible]	25.9	1.7	[illegible]	3.1		2.3		.5	[illegible]
[illegible]	15.4	1.1	[illegible]	1.0				1.8	21.8
Year	[illegible]	[illegible]	339.7	117.3	[illegible]	[2] 103.6	[illegible]	[illegible]	1,675.0

[illegible]

TABLE 194.—*Mountain run-off to southwest area, San Luis Valley*—Continued

[illegible]	Northern group: [illegible] Norte, 1,320 [illegible] miles	[illegible] square miles	[illegible] square miles	[illegible] Reservoir, 115 square miles	Southern group: [illegible] square miles	[illegible] miles	[illegible]	[illegible] square [illegible]	Total
[illegible]									
January	[illegible]	[illegible]	[illegible]	3.1		(1)		3.6	23.6
February	[illegible]	[illegible]	[illegible]	2.3	[illegible]	(1)	[illegible]	4.8	[illegible]
March	17.[illegible]	1.6	3.4	2.3	(1)	2.4	[illegible]	[illegible]	30.5
April	56	8.0	33.3	9.2	(1)	28.0	(1)	28.0	162.6
May	98	7.0	54.0	15.5	3.7	38.6	6.6	5.0	228.7
June	120	4.0	63.7	17.8	2.0	16.8	.6	1.9	227.3
July	57.[illegible]	3.5	[illegible]	6.9	1.1	3.1		.4	91.0
August	50	3.5	14.0	6.4	1.0	3.0		[illegible]	79.2
September	23.[illegible]	2.5	3.4	1.9	[illegible]	1.2	[illegible]	0	[illegible]
October	[illegible]	1.5	3.8	1.6	.3	1.4		[illegible]	[illegible]
November	[illegible]	[illegible]	1.8	1.8	[illegible]	[illegible]	[illegible]	[illegible]	23.2
December	[illegible]	[illegible]	[illegible]	1.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Year	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]									
January	[illegible]	[illegible]	[illegible]	1.1	[illegible]	[illegible]	[illegible]	2.0	[illegible]
February	10.3	[illegible]	1.8	.9	(1)	[illegible]	[illegible]	2.6	16.6
March	14.1	1.3	3.1	1.1	(1)		(1)	3.8	23.4
April	28.0	1.5	11.7	2.9	(1)	6.1	(1)	8.0	58.2
May	74.2	7.0	38.1	12.8	2.4	17.6	[illegible]	3.3	160.4
June	87.7	4.0	40.8	11.9	.7	7.3	.1	1.1	153.6
July	29.7	1.7	9.6	3.0	.4	2.3	0	.2	[illegible]
August	18.0	[illegible]	9.2	2.8	.5	[illegible]	.1	0	33.2
September	23.1	1.7	12.7	4.8	.7	[illegible]	0	0	44.4
October	30.4	2.0	13.2	5.3	[illegible]	2.2	[illegible]	1.3	[illegible]
November	14.7	1.0	4.3	1.4	(1)	(1)	[illegible]	[illegible]	23.6
December	13.6	1.0	4.3	1.5	(1)	(1)	[illegible]	3.0	23.4
Year	353.0	24.6	150.6	49.5	[illegible]	[illegible]	[illegible]	[illegible]	653.1
[illegible]									
January	13.9	1.2	3.2	1.3	[illegible]	[illegible]	[illegible]	3.2	22.8
February	14.2	1.3	3.1	1.6	[illegible]		[illegible]	4.3	24.5
March	19.0	1.7	5.1	1.5	[illegible]	[illegible]	[illegible]	4.0	35.6
April	60.4	6.0	30.1	8.9	3.8	18.4	12.0	4.0	143.6
May	275.3	27.0	168.0	35.1	9.1	67.0	18.8	12.2	552.5
June	264.1	21.0	118.0	37.6	[illegible]	38.0	1.9	1.3	482.8
July	[illegible]	9.0	54.6	20.8	[illegible]	13.1	.4	0	225.8
August	65.3	4.2	18.6	3.9	[illegible]	2.6	.3	0	95.0
September	27.6	1.8	6.5	2.0	[illegible]	1.2	.1	0	39.6
October	20.7	[illegible]	[illegible]	1.4	[illegible]	1.5	.3	[illegible]	29.8
November	[illegible]	1.0	2.9	1.1	[illegible]	[illegible]	[illegible]	[illegible]	20.7
December	12.7	1.0	2.6	1.1	[illegible]	[illegible]	[illegible]	2.0	19.4
Year	915.0	76.6	357.2	116.3	[illegible]	[illegible]	[illegible]	33.8	1,692.1
[illegible]									
January	12.8	1.2	2.8	.9	[illegible]	[illegible]	[illegible]	2.6	20.3
February	10.4	[illegible]	2.2	1.1	(1)	(1)	[illegible]	3.1	17.8
March	16.9	1.5	4.4	1.1	[illegible]		(1)	5.5	29.4
April	19.9	.7	9.7	1.9	[illegible]	6.0	3.6	1.9	45.0
May	82.6	7.0	44.4	16.0	[illegible]	30.8	9.9	4.3	198.2
June	182.1	10.0	93.4	33.4	[illegible]	26.3	2.7	1.2	349.9
July	53.8	3.7	27.2	9.2	[illegible]	5.1	.5	.1	100.0
August	[illegible]	2.6	11.3	2.3	[illegible]	2.0	.1	0	57.9
September	26.9	1.7	8.3	1.9	[illegible]	1.8	.1	0	[illegible]
October	24.2	1.5	7.1	1.5	[illegible]	1.6	.2	0	36.5
November	19.1	1.3	3.9	[illegible]	[illegible]	1.3	.1	[illegible]	27.0
December	16.2	1.2	2.5	[illegible]	(1)	(1)	(1)	1.6	22.1
Year	[illegible]	33.4	217.2	70.8	[2] 7.6	[2] 74.9	[2] 17.2	20.3	945.2
1934									
January	15.6	1.5	2.2	.6	[illegible]	(1)	[illegible]	2.0	21.9
February	13.6	1.3	2.5	1.6	[illegible]	[illegible]	(1)	4.0	23.0
March	[illegible]	1.5	[illegible]	1.6	(1)	[illegible]	[illegible]	7.0	32.3
April	[illegible]	14.0	30.5	13.0	1.2	14.8	2.0	1.6	141.6
May	97.7	7.0	36.1	10.9	[illegible]	7.0	.3	1.0	160.7
June	26.7	.5	7.0	2.6	[illegible]	1.6	0	.4	39.1
July	13.5	.4	4.3	.9	[illegible]	.8	0	[illegible]	19.9
August	14.7	1.0	4.0	[illegible]	[illegible]	.9	.1	0	22.4
September	17.4	[illegible]	4.4	[illegible]	[illegible]	1.1	.1	0	25.6
October	14.6	1.0	3.3	[illegible]	[illegible]	[illegible]	.1	[illegible]	21.3
November	11.0	.8	2.6	[illegible]	[illegible]	[illegible]	.1	0	16.2
December	10.3	.8	1.9	[illegible]	[illegible]	(1)	(1)	1.0	14.9
Year	316.4	30.9	104.2	36.2	[2] 3.5	[2] 27.9	[2] 2.7	[illegible]	538.9

[1] Where no figure is given the run-off was not measured and its estimate has been included in the estimate for the unmeasured area.
[2] Partial year. Missing months are included in the total for the unmeasured area.

TABLE 194.—[illegible]—Continued

[illegible]	[illegible] near Del Norte, 1,320 square miles	[illegible] Creek near Del Norte, [illegible] miles	[illegible] Creek near Monte [illegible]	[illegible]	Conejos River near Mogote, [illegible]	[illegible]	[illegible]	[illegible]	San Antonio River at Ortiz, [illegible]	Unmeasured, 136 [illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.9	[illegible]	[illegible]	[illegible]	[illegible]	2.0	16.0
[illegible]	11.1	[illegible]	[illegible]	[illegible]	2.4	[illegible]	[illegible]	[illegible]	[illegible]	3.0	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.3	1.5	(¹)	[illegible]	[illegible]	6.0	29.0
[illegible]	[illegible]	[illegible]	[illegible]	1.8	[illegible]	[illegible]	3.0	[illegible]	[illegible]	4.4	75.2
[illegible]	[illegible]	[illegible]	[illegible]	4.0	[illegible]	[illegible]	6.5	40.3	13.3	8.7	217.3
June	[illegible]	[illegible]	3.3	30.0	[illegible]	[illegible]	[illegible]	42.3	[illegible]	[illegible]	[illegible]
[illegible]	117.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.3	0	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.4	.3	0	[illegible]
[illegible]	40.5	[illegible]	[illegible]	[illegible]	[illegible]	2.4	[illegible]	1.7	[illegible]	[illegible]	45.4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.4	[illegible]	[illegible]	24.7
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	(²)	.1	0	22.1
[illegible]	11.6	[illegible]	[illegible]	[illegible]	2.4	.6	[illegible]	[illegible]	[illegible]	0	[illegible]
Total	720.1	[illegible]	[illegible]	52.9	[illegible]	[illegible]	²11.2	²106.8	[illegible]	[illegible]	1,355.5
[illegible]	[illegible]				255.5						1,258.6

¹ [illegible]

² Partial year. Missing months are included in the total for the unmeasured area.

[illegible] the derived natural flow figures for the Rio Grande and Conejos for the 46-year period and, except for the period of record of the other streams, including their drainages as a part of the total of unmeasured drainage area, estimates were completed to give the monthly water production for the entire southwest area, 1890–1935, as shown by table 194. In these estimates the run-off for the unmeasured drainage areas was derived by comparison to that for adjacent measured areas of like characteristics to the extent permitted by the period of record of the latter and finally the run-off for the northern and southern groups as a whole was extended to 1890 on the basis of curves of monthly run-off relations to the Rio Grande and Conejos River, respectively. All records, no matter how short, were therefore taken into account in the estimates.

As shown by table 194, the mean annual water production from mountain run-off in the period 1890–1935 for the southwest area was determined to be 1,259,000 acre-feet. Although considerable estimating was involved in this determination, it is to be noted that 77 percent of the total run-off accounted for in table 194 was measured and only 23 percent is based upon estimates.

In the southeast area, east of the Rio Grande and between the closed basin on the north and the Colorado-New Mexico State line on the south, the principal streams are Trinchera and Culebra Creeks. On the south, Costilla River flows for a few miles in Colorado but its source is in New Mexico and it joins the Rio Grande in the latter State. Although the water of Costilla River is largely consumed on Colorado lands, the production estimate for this river is, for this report, included in the Middle section of New Mexico [illegible] production. For the southeast area the water production derived is that for the mountain run-off at the rim of the valley floor or the foothill line. The available run-off records are as follows:

Trinchera Creek above Mountain Home Reservoir, 61 square miles, 1908, 1909, 1923–35.

Sangre de Cristo Creek near Fort Garland, 176 square miles, 1916, 1923–29, 1932–35.

Ute Creek near Fort Garland, 32 square miles, 1908, 1909, 1916, 1923–35.

Culebra Creek at San Luis, 220 square miles, 1909–19, 1927–35.

Except for Culebra Creek, and in some years for Trinchera Creek, these records do not include the winter months.

Dividing the area into north and south sections, the unmeasured drainage area of the north is 24 square miles and that of the south 53 square miles. The only regulation above the gaging stations is that of the Sanchez Reservoir on a Culebra Creek tributary and correction was made for this to give natural flow.

Because of the paucity of data, estimates of annual flow only were made in extending the records to the 46-year period 1890–1935. The annual run-off of Culebra Creek was extended by comparison with the natural run-off of the Rio Grande near Del Norte. Partial year records for Ute, Sangre de Cristo, and Trinchera creeks were completed by comparison with Culebra Creek record. The annual run-off of Sangre de Cristo Creek for the missing years 1908, 1909, 1930, and 1931 was estimated by comparison with the combined run-off of the other streams. The annual run-off, 1908, 1909, and 1923 to 1935, of unmeasured streams was derived by comparison with the run-off per square mile of measured streams. The unit run-off for the northern unmeasured area was taken at 75 percent of that for Ute

Creek, and that for the southern unmeasured area as 75 percent of that for Culebra Creek. The combined annual run-off of all streams except Culebra Creek was estimated for the years 1910 to 1919 by using curves of annual run-off relations to Culebra Creek, and for the years 1890 to 1907 and 1920 to 1922 by similar curves giving the relation to the run-off of Rio Grande near Del Norte. The estimates of annual water production so derived for the southeast area are shown in table 195. As indicated, the mean annual water production for this area was determined to be 120,400 acre-feet. As previously stated, very little of this production reaches the Rio Grande, practically all of it being consumed in irrigation between the foothills and the river.

In the closed basin area the streams enter the valley around its semicircular rim and flow toward the sump area extending along the base of the Sangre de Cristo Range. Such waters of the streams and of the diversions from the Rio Grande that are not consumed in irrigation, by transpiration of native vegetation, or by evaporation, finally find their way to the sump. Here, in seasons of abundant run-off the waste waters collect in numerous small lakes, swamps, and low water-logged areas and are evaporated. In seasons of moderate run-off the areas of free water surface and swamp are greatly diminished, and after a series of dry years San Luis and Head Lakes constitute the only free water surfaces. Observations seem to indicate that a substantial fraction of the water production of the east side streams escapes to the artesian basin which underlies the valley and reaches some distance under the delta fan of each of the streams entering it. Records of the closed basin run-off entering the valley at the foothill line are available as follows:

La Garita Creek near La Garita, 61 square miles, 1919–35.
Carnero Creek near La Garita, 117 square miles, 1919–35.
Saguache Creek near Saguache, [illegible] square miles, 1910–12, 1914–35.

TABLE 195.—*Mountain run-off to southeast area, San Luis Valley, Colo.*

[Estimated natural run-off at rim of valley]

[Drainage area 566 square miles. Unit, 1,000 acre-feet]

Year	Culebra Creek at San Luis, [illegible] square miles	Trinchera Creek [illegible] Mountain Home Reservoir, 61 square miles	Sangre de Cristo Creek near Fort Garland, [illegible] square miles	Ute Creek near Fort Garland, 32 square miles	Northern group, unmeasured, [illegible] square miles	Southern group, unmeasured, 53 square miles	Sum of [illegible] inclusive	Total	Percent [illegible] year
	(1)	(2)	(3)	(4)	(5)	(6)	[illegible]	[illegible]	[illegible]
1890	52.0						77.0	129.0	[illegible]
1891	[illegible]						79.0	134.0	111
1892	[illegible]						58.0	98.0	81
1893	33.0						49.0	82.0	68
1894	35.0						51.0	86.0	71
1895	45.0						66.0	111.0	[illegible]
1896	38.0						55.0	[illegible]	[illegible]
1897	54.0						77.0	131.0	109
1898	52.0						76.0	128.0	106
1899	[illegible]						49.0	82.0	[illegible]
1900	[illegible]						56.0	95.0	79
1901	[illegible]						55.0	93.0	78
1902	[illegible]						39.0	[illegible]	[illegible]
1903	50.0						75.0	[illegible]	104
1904	34.0						49.0	83.0	69
1905	55.0						79.0	134.0	111
1906	59.0						[illegible]	145.0	120
1907	69.0						100.0	169.0	140
1908	41.0	13.2	17.5	12.9	7.2	7.7	[illegible]	99.5	83
1909	67.0	12.8	19.9	18.2	10.3	12.7	73.9	140.9	117
1910	[illegible]						78.5	128.9	107
1911	[illegible]						79.0	129.8	108
1912	59.5						89.0	148.5	123
1913	34.2						60.0	[illegible]	[illegible]
1914	62.8						[illegible]	[illegible]	[illegible]
1915	70.3						[illegible]	171.3	143
1916	52.4						[illegible]	133.1	111
1917	60.5						90.0	[illegible]	[illegible]
1918	56.2						85.0	141.2	117
1919	72.0						103.0	175.0	145
1920	62.0						90.0	152.0	126
1921	63.0						90.0	[illegible]	[illegible]
1922	59.0						[illegible]	143.0	119
1923	56.0	9.4	[illegible]	[illegible]	11.5	[illegible]	[illegible]	123.9	103
1924	49.0	16.9	46.6	23.6	13.2	9.3	109.6	158.6	[illegible]
1925	50.0	4.6	6.7	9.8	5.5	[illegible]	[illegible]	[illegible]	[illegible]
1926	45.0	26.5	[illegible]	7.0	3.9	[illegible]	79.7	124.7	104
1927	42.9	11.5	11.9	19.6	10.9	8.1	62.0	104.9	87
1928	[illegible]	17.1	24.0	16.3	9.1	7.1	73.6	111.5	93
1929	38.8	12.4	15.4	24.7	13.9	7.3	73.7	112.5	[illegible]
1930	39.9	14.9	19.3	14.8	8.3	7.5	64.8	[illegible]	87
1931	29.3	11.1	16.7	20.2	11.3	5.6	64.9	94.2	78
1932	41.1	17.8	25.6	27.8	15.6	7.9	94.7	[illegible]	113
1933	40.3	18.4	[illegible]	14.3	8.0	7.6	66.7	107.0	[illegible]
1934	29.6	7.8	7.3	9.7	5.4	5.6	35.6	65.2	54
1935	42.2	15.5	13.5	19.8	11.1	7.9	67.8	110.0	91
[illegible] year mean	48.1						72.3	120.4	

San Luis Creek near Villa Grove, 255 square miles, 1922–26.

[illegible] North and South Crestone, [illegible], Cottonwood, and Deadman, all near Crestone, 43 square miles, 1909, 1915, 1936.

Sand Creek near Crestone, in Group C, drainage area 102 square miles, 1936 only.

Of these records, only those for Saguache Creek include any winter months, and the others are, for the most part, only for the period May to October.

For estimating purposes the east side area below Villa Grove was divided into three stream groups. Group A, an unmeasured run-off drainage area of 72 square miles above the foothill line, includes Cotton, Wild Cherry, Rito Alto, and San Isabel Creeks. Group B, 43 square miles, includes the creeks as given in the above list of available records. Group C, 102 square miles, includes Pole, Sand, Medano, Zapato, and other small creeks south to the closed basin boundary, and is unmeasured except for the 1936 record on Sand Creek.

It will be noted that the run-off records for the closed basin are exceedingly meager as the basis for a long-time production estimate. Although estimates of the annual mountain run-off at the foothill line, or approximately 8,500-foot contour, were made for the 46-year period, 1890–1935 so as to be comparable with the estimates for other areas, attention is directed to the fact that the estimates for the earlier years may be somewhat wide since they were necessarily based for much of the period on a comparison to the run-off of the Rio Grande near Del Norte, which shows a rather poor correlation with closed basin run-off.

Incomplete years in the longest recorded period, that for Saguache Creek, 1911, 1912, and 1914–35, were completed by a comparison to the monthly distribution relation as shown by Rio Grande near Del Norte for concurrent years. Incomplete and missing years for the same period for La Garita, Carnero, and San Luis Creeks were estimated by reference to the Saguache Creek record; incomplete years by comparison to the monthly distribution relation shown by Saguache Creek for concurrent years, and missing years from curves of annual run-off relations to Saguache Creek. The sum of the annual run-offs of Saguache, La Garita, Carnero, and San Luis Creeks for the period 1911, 1912, and 1914–35 was then referred to the Rio Grande near Del Norte record to complete the annual estimates for this combined run-off for the period 1890–1935.

The estimates for the east side streams in groups A, B, and C were treated separately. Draining from the east, they were assumed to bear a closer relation to Trinchera and Culebra Creeks than to the western streams. For the streams of group B an estimated curve of relation to Culebra Creek run-off at San Luis was drawn by plotting the 1936 May–September run-off, the 1909 and 1915 April–October run-off, and the extended annual run-offs for these years against the run-off of Culebra Creek for corresponding periods. The annual run-offs of Culebra Creek, including years estimated from the Rio Grande near Del Norte, were then applied to this curve to derive the estimates of annual run-off for group B streams, 1890–1936. The mean of these estimates was determined to be 32,700 acre-feet.

The mean annual run-off from group A streams was estimated by a comparison to the 46-year mean annual yields per square mile of San Luis Creek on the north and group B streams on the south, estimated at 45 and 760 acre-feet per square mile, respectively. The northern part of group A area, comprising 37 square miles, was considered to have a unit run-off greater than San Luis Creek but much less than the southern part of the area. The northern part was therefore assumed to have a mean annual run-off of 150 acre-feet per square mile, while the 35 square miles of the southern part was assumed to have a unit run-off of 700 acre-feet per square mile. This gave a composite mean annual run-off for group A of 417 acre-feet per square mile, or 30,000 acre-feet, as the estimated annual mean for the 1890–1935 period. The annual figures for group A were derived by direct proportion to those for group B.

The mean annual run-off from group C streams was estimated by comparison of the 1936 May to September run-off of Sand Creek, assumed to represent one-third of the run-off of the entire group, with the run-off from group B streams for the same period. This gave a ratio of 30 to 26 which, applied to the estimated 32,700 acre-feet mean for group B, gave an estimate of 38,000 acre-feet for the 1890–1935 mean annual run-off of group C streams. Annual figures for group C were derived by direct proportion to those for group B as in the case of group A.

The summation of the water production estimates for the closed basin is given in table 196. This shows an estimated total mean annual production of 187,700 acre-feet.

In table 197 the estimates of annual production for the southwest, southeast and closed basin areas are brought together to give the totals for the San Luis section. As indicated, the total mean annual production 1890–1935 for this section was determined to be 1,567,000 acre-feet. This may also be taken as the Colorado production, although it is not strictly so since a part of the Los Pinos River watershed and all of the San Antonio River watershed above the gaging stations near Ortiz lie in New Mexico. The run-off from these New Mexico areas is included in the San Luis section production since the Los Pinos and San Antonio Rivers are tributary to the Conejos River which joins the Rio Grande in San Luis Valley. In the estimate of water production for the Middle Section in New Mexico all of the run-off of the watershed of the Rio Chama, which

TABLE 196.—*Mountain run-off to closed basin area, San Luis Valley, Colo.*

[Estimated natural run-off at rim of valley]

[Drainage area, 1,140 square miles. Unit, 1,000 acre-feet]

Year	La Garita Creek near La Garita, [illegible] square miles	Carnero Creek near La Garita, 117 square miles	Saguache Creek near Saguache, 490 square miles	San Luis Creek near Villa Grove, [illegible] square miles	[illegible] inclusive, 923 square miles	[illegible]			Total (5) to (8), inclusive	Percent of 46-year mean
						Group A, 72 square miles	Group B, 43 square miles	Group C, [illegible] square miles		
(1)	[illegible]	(2)	[illegible]	[illegible]	(5)	[illegible]	[illegible]	[illegible]	[illegible]	(10)
1890					[illegible]	32.0	[illegible]	41.0	[illegible]	[illegible]
1891					105.0	33.0	36.0	42.0	216.0	[illegible]
1892					65.0	27.0	29.0	34.0	155.0	[illegible]
1893					48.0	24.0	26.0	30.0	128.0	[illegible]
1894					52.0	25.0	27.0	31.0	[illegible]	[illegible]
1895					80.0	28.0	31.0	36.0	175.0	[illegible]
1896					[illegible]	26.0	28.0	33.0	117.0	78
1897					101.0	32.0	35.0	[illegible]	209.0	[illegible]
1898					98.0	32.0	35.0	41.0	206.0	110
1899					48.0	21.0	26.0	30.0	[illegible]	[illegible]
1900					62.0	26.0	28.0	33.0	[illegible]	[illegible]
1901					60.0	26.0	28.0	33.0	147.0	[illegible]
1902					30.0	21.0	23.0	27.0	101.0	[illegible]
1903					93.0	31.0	34.0	39.0	[illegible]	[illegible]
1904					50.0	24.0	26.0	30.0	130.0	[illegible]
1905					105.0	33.0	36.0	42.0	216.0	[illegible]
1906					116.0	35.0	38.0	44.0	233.0	[illegible]
1907					143.0	39.0	43.0	50.0	275.0	147
1908					67.0	27.0	29.0	34.0	157.0	[illegible]
1909					[illegible]	40.0	44.0	51.0	216.0	[illegible]
1910					80.0	31.0	34.0	39.0	184.0	98
1911	22.0	15.0	73.3	9.6	119.9	31.0	34.0	39.0	[illegible]	[illegible]
1912	17.0	12.0	60.4	17.0	106.4	35.0	38.0	44.0	[illegible]	[illegible]
1913					70.0	24.0	26.0	30.0	150.0	80
1914	20.0	13.0	67.1	14.0	114.1	37.0	40.0	[illegible]	[illegible]	[illegible]
1915	17.0	11.0	59.3	[illegible]	97.3	35.0	38.0	44.0	214.3	[illegible]
1916	18.0	12.0	62.1	11.0	103.1	32.0	35.0	[illegible]	211.1	[illegible]
1917	20.0	13.0	66.2	13.0	112.2	36.0	39.0	45.0	[illegible]	[illegible]
1918	12.0	9.0	48.3	3.5	72.8	34.0	37.0	43.0	186.8	[illegible]
1919	23.6	20.2	77.3	20.0	141.1	40.0	44.0	51.0	276.1	147
1920	[illegible]	12.3	[illegible]	15.0	110.4	37.0	40.0	46.0	233.4	124
1921	22.5	11.5	[illegible]	21.0	133.5	37.0	40.0	46.0	[illegible]	137
1922	11.7	9.9	51.7	4.7	78.0	35.0	38.0	44.0	[illegible]	104
1923	20.2	14.3	66.0	12.4	112.9	34.0	37.0	43.0	226.9	121
1924	29.8	27.0	83.7	33.4	173.9	[illegible]	33.0	38.0	274.9	[illegible]
1925	11.7	7.3	51.5	4.9	75.4	30.0	33.0	[illegible]	176.4	94
1926	16.6	10.9	59.5	[illegible]	99.6	28.0	31.0	36.0	194.6	104
1927	[illegible]	4.8	57.5	8.5	77.2	28.0	[illegible]	35.0	170.2	91
1928	9.6	[illegible]	73.6	[illegible]	118.7	26.0	28.0	33.0	205.7	110
1929	13.0	12.4	70.0	16.0	111.4	26.0	[illegible]	33.0	198.4	106
1930	8.8	8.1	38.8	1.3	57.0	27.0	29.0	34.0	147.0	78
1931	4.4	3.8	27.3	1.0	[illegible]	[illegible]	[illegible]	28.0	110.5	[illegible]
1932	[illegible]	4.8	54.0	6.2	72.4	27.0	29.0	34.0	[illegible]	87
1933	5.6	4.3	33.7	[illegible]	44.6	27.0	29.0	34.0	131.6	[illegible]
1934	3.5	2.8	20.6	.8	27.7	22.0	24.0	28.0	101.7	54
1935	9.2	8.6	42.1	1.5	[illegible]	28.0	30.0	35.0	149.9	80
[illegible] mean					87.0	30.0	32.7	38.0	187.7	..

joins the Rio Grande in New Mexico, is included, although there is a portion of this watershed in Colorado. The latter is a somewhat smaller area than that drained by Los Pinos and San Antonio Rivers in New Mexico, but its run-off largely offsets that from this latter area as the Rio Chama drains an area of considerably higher average elevation and greater average precipitation.

Water Production in the Middle Section, New Mexico

In estimating the water production, this section was divided into northern and southern units. In the northern unit were included all streams entering the Rio Grande between the Colorado-New Mexico State line and Otowi Bridge at the upper end of White Rock Canyon, and in the southern unit those entering between Otowi Bridge and San Marcial. The production estimates represent the run-off at the foothill line available for use in the valley areas, and no account is taken of possible run-off from precipitation on the valley

TABLE 197.—*Mountain run-off to San Luis section, Rio Grande Basin, Colo.*

[Estimated natural run-off at rim of valley]

[Drainage area, 4,098 square miles. Unit, 1,000 acre-feet]

Year	Southwest area				[illegible] area, [illegible] square miles	Closed basin, 1,140 square miles	Total	Percent of 46-year mean
	Rio Grande near Del Norte, 1,320 square miles	[illegible] River near [illegible], [illegible] square miles	Sum of other streams, [illegible] square miles	Total, 2,392 square miles				
1890	820	301	369	1,490	129	209	1,828	117
1891	860	311	372	1,543	[illegible]	216	1,893	121
1892	532	193	233	958	98	155	1,211	77
1893	392	141	158	691	82	128	[illegible]	58
1894	424	151	191	766	86	135	987	[illegible]
1895	650	233	301	1,184	111	175	1,470	94
1896	487	171	241	899	93	147	1,139	73
1897	823	291	344	[illegible]	131	209	1,798	115
1898	[illegible]	[illegible]	366	1,459	128	206	1,793	114
1899	393	134	146	673	82	128	883	[illegible]
1900	[illegible]	187	212	905	95	149	[illegible]	[illegible]
1901	487	178	209	874	93	147	1,114	71
1902	249	87	105	441	[illegible]	101	608	39
1903	760	314	334	[illegible]	[illegible]	197	1,730	110
1904	406	150	148	704	83	130	917	58
1905	853	318	361	1,532	134	216	1,882	120
1906	949	334	378	1,661	[illegible]	233	2,039	130
1907	1,164	356	[illegible]	1,914	169	275	2,358	150

[illegible] *Basin, Colo.*—Continued

[illegible]	[illegible]	[illegible] square miles	Sum of other [illegible] square miles	Total, [illegible]	South east [illegible] square miles	[illegible]	Total	[illegible]
[illegible]	[illegible]	193	190	933	[illegible]	157	1,189	76
[illegible]	[illegible]	323	370	1,602	[illegible]	246	1,989	127
1910	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	184	1,462	[illegible]
1911	[illegible]	[illegible]	[illegible]	1,913	130	224	2,267	145
1912	812	308	384	[illegible]	149	223	1,876	120
[illegible]	[illegible]	[illegible]	180	913	94	[illegible]	1,157	74
[illegible]	[illegible]	[illegible]	275	1,348	156	237	1,741	111
[illegible]	[illegible]	258	[illegible]	1,142	171	214	1,527	97
[illegible]	[illegible]	[illegible]	[illegible]	1,724	133	211	[illegible]	132
[illegible]	913	320	398	[illegible]	[illegible]	232	2,013	128
[illegible]	517	[illegible]	221	[illegible]	[illegible]	[illegible]	1,292	82
[illegible]	795	[illegible]	351	1,392	175	[illegible]	1,843	[illegible]
[illegible]	1,015	[illegible]	[illegible]	[illegible]	152	[illegible]	[illegible]	149
[illegible]	1,026	[illegible]	233	[illegible]	153	256	1,928	123
1922	[illegible]	[illegible]	373	1,613	143	195	1,951	124
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	124	227	2,018	[illegible]
[illegible]	748	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	117
[illegible]	[illegible]	233	[illegible]	1,228	[illegible]	[illegible]	1,490	[illegible]
[illegible]	[illegible]	249	[illegible]	[illegible]	125	[illegible]	1,473	[illegible]
[illegible]	[illegible]	341	372	1,736	[illegible]	[illegible]	2,011	[illegible]
[illegible]	[illegible]	192	[illegible]	[illegible]	[illegible]	206	1,357	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	198	1,986	127
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	105	[illegible]	1,232	79
[illegible]	[illegible]	151	[illegible]	653	94	110	857	[illegible]
[illegible]	[illegible]	357	420	1,692	136	162	[illegible]	127
[illegible]	[illegible]	217	221	945	107	[illegible]	1,187	76
1934	416	[illegible]	[illegible]	539	[illegible]	102	706	45
[illegible]	[illegible]	[illegible]	337	[illegible]	[illegible]	150	1,646	103
[illegible]	710	256	293	1,259	120	88	1,567	

[illegible]. The foothill line varies from about 8,200 feet elevation in the north to about 5,500 feet in the south and due consideration was given to this fact in estimating the run-off from drainage areas having no stream-flow records.

The northern unit was divided into run-off from the east and from the west. Available records for eastern streams, above diversions, are as follows:

Costilla River at mouth of canyon, 229 square miles, 1907, 1908, 1911–17, 1920.

Rio Colorado below Cabresto Creek, [illegible] square miles, 1913–28.

Rio Hondo at Valdez, 38 square miles, 1917–35.

Rio [illegible] near Taos, 64 square miles, 1913–28.

Rio Lucero near Arroyo Seco, 17 square miles, 1912–28.

Rio [illegible] near Taos, 67 square miles, 1911.

Rio Santa Cruz at Cundiyo, 86 square miles, 1930–35.

Nambe Creek near Nambe, 37 square miles, 1933–35.

Contributing areas on the east, unmeasured above diversions, include Latir Creek, Arroyo Seco, Rio Chiquito, Embudo Creek, Truchas River, Rio Frijoles, Tesuque Creek, and minor streams, totaling 506 square miles.

Available records for western streams are confined to Rio Chama and its tributaries. Records of the Rio Chama at Chamita, near the mouth, are available for the period 1913 to 1936. Unmeasured contributing areas not tributary to Rio Chama include principally [illegible] and Santa Clara River, totaling 230 square miles.

The period 1907–35 was taken for the extension of individual eastern stream records, and estimates of annual run-off to fill out the period were made by comparison with the available records. In addition to the records listed, use was made of the record of Culebra Creek at San Luis, corrected for storage regulation, and of that for Rio Colorado above Cabresto Creek. Estimates were made either by annual relation curves based upon the period of concurrent record or by assuming the same relation to have existed for missing years as was shown by the years of concurrent record. Where possible, estimates were based on the comparative relation to two streams rather than to one. The mean annual run-off 1907–35 for the unmeasured streams was estimated by direct comparison to the mean annual run-off per square mile of measured streams adjacent or considered to have drainage characteristics similar to those of the unmeasured stream. The means for the unmeasured streams were then combined and estimates of the annual run-off 1907–35 for the total unmeasured area derived by assuming the annual run-offs to bear the same relation to the period mean that the annual run-offs for the total of the measured streams bore to their period mean. The total annual run-off for all eastern streams, 1890–1907, was estimated by reference to the gain in the Rio Grande between the Lobatos and Embudo stations using a relation curve established for the years of concurrent data.

For the western streams, the record of Rio Chama near Chamita was corrected for upstream irrigation on the basis of the 1936 acreages and consumptive use figures reported by the Bureau of Agricultural Engineering (Part III of this report). The irrigation draft was derived by applying the unit consumptive use figures less precipitation to the acreages of the various classifications including irrigated land, native vegetation, water surfaces and the like, and was found to total 70,000 acre-feet. This was used as a constant correction for each year on the assumption that there would have been no shortage of Rio Chama run-off to supply this draft. The corrected Chamita flow is shown in column 11 of table 198. The mean run-off of the unmeasured streams, 1913–35, was taken at 150 acre-feet per square mile from comparison with that of the Rio Chama and other northern unit streams. For the 230 square miles of unmeasured area this gave a run-off of 35,000 acre-feet. This mean was distributed to the years 1913–35 in accordance with the distribution of the Rio Chama run-off in the same period, as shown in column 12, table 198. The total annual run-off for western streams, 1890 to 1912, was estimated by reference to the gain in the Rio Grande between Embudo and Otowi Bridge using a relation curve established for the years of concurrent data. Gains in this river section are largely the result of west side inflow.

TABLE 198.—Mountain run-off to northern unit, middle section, Rio Grande Basin, New Mexico

[Estimated] virgin run-off at foothill line of valleys, Colorado-New Mexico State line to Otowi Bridge

[Drainage area 4,641 square miles. Unit, 1,000 acre-feet]

Year	Eastern streams: Costilla Creek at Canyon mouth, [illegible] square miles	Rio [illegible] below [illegible] Creek, 165 square miles	Rio Hondo at Valdez, [illegible] square miles	Rio Fernando de Taos near Taos, [illegible] square miles	Rio Lucero near Arroyo Seco, 17 square miles	Rio Pueblo de Taos near Taos, [illegible] square miles	Rio Santa Cruz at Cundiyo, [illegible] square miles	[illegible] Creek near [illegible], 37 square miles	Unmeasured streams, [illegible] square miles	Total (1) to (9) inclusive, 1,209 square miles	Western streams: Rio Chama near Chamita, 3,202 square miles	Unmeasured streams, 230 square miles	Total sum of (11) and (12), 3,432 square miles	Total (10) and (13)	[illegible] of 16-year mean
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
1890										410.0			830.0	1,240.0	[illegible]
1891										470.0			1,040.0	1,510.0	159.4
1892										370.0			860.0	1,230.0	129.8
1893										310.0			480.0	790.0	[illegible]
1894										324.0			180.0	[illegible]	53.2
1895										350.0			660.0	1,010.0	106.6
1896										240.0			290.0	530.0	[illegible]
1897										410.0			[illegible]	1,370.0	144.5
1898										350.0			300.0	650.0	[illegible]
1899										210.0			380.0	590.0	62.3
1900										230.0			220.0	450.0	47.5
1901										295.0			370.0	665.0	70.2
1902										200.0			180.0	380.0	40.1
1903										415.0			[illegible]	1,215.0	128.2
1904										237.0			390.0	627.0	66.2
1905										450.0			790.0	1,240.0	130.9
1906										430.0			830.0	[illegible]	133.0
1907	38.0	42.0	15.0	6.0	15.0	16.0	21.0	9.0	104.0	266.0			[illegible]	1,216.0	128.3
1908	59.0	66.0	24.0	12.0	22.0	28.0	34.0	14.0	167.0	426.0			600.0	1,026.0	108.3
1909	64.0	72.0	26.0	13.0	21.0	30.0	37.0	16.0	181.0	463.0			[illegible]	1,223.0	129.1
1910	19.0	54.0	20.0	9.0	19.0	22.0	28.0	12.0	137.0	350.0			470.0	820.0	86.5
1911	38.2	42.0	25.0	12.0	21.7	27.5	27.0	12.0	134.0	342.4			[illegible]	1,212.4	127.9
1912	67.6	51.0	10.0	8.0	18.3	27.2	31.0	13.0	151.0	386.1			800.0	1,186.1	125.2
1913	28.5	30.7	12.0	4.2	13.7	12.8	16.0	7.0	80.0	204.9	349.1	22.0	371.1	576.0	[illegible]
1914	19.2	56.8	21.0	9.3	20.0	17.6	28.0	12.0	138.0	351.9	553.1	35.0	588.1	940.0	99.2
1915	[illegible]	76.2	23.0	12.8	[illegible]	28.1	37.0	16.0	220.0	503.9	735.3	46.0	781.3	1,285.2	135.6
1916	47.8	80.9	40.0	10.2	34.0	48.0	42.0	18.0	206.0	526.9	977.2	61.0	1,038.2	1,565.1	165.2
1917	54.3	58.4	25.0	[illegible]	23.0	29.0	31.0	13.0	152.0	388.5	549.6	34.0	[illegible]	972.1	102.6
1918	47.0	47.3	16.7	4.4	17.0	19.0	24.0	10.0	120.0	305.4	329.4	21.0	350.4	655.8	69.2
1919	68.0	62.9	18.2	13.8	18.0	20.0	32.0	14.0	159.0	405.9	688.9	43.0	731.9	1,137.8	120.0
1920	54.3	90.2	25.0	[illegible]	21.0	27.0	36.0	15.0	177.0	454.1	856.4	53.0	[illegible]	1,363.5	[illegible]
1921	109.0	82.2	28.9	6.9	26.0	34.0	46.0	20.0	227.0	580.0	499.4	33.0	532.4	1,112.4	117.4
1922	32.0	33.0	9.2	4.3	11.0	9.0	16.0	7.0	77.0	198.5	411.4	26.0	437.4	635.9	67.1
1923	50.0	44.0	18.7	3.7	19.0	21.0	25.0	11.0	124.0	316.4	575.8	35.0	610.8	927.2	97.8
1924	93.0	77.0	30.4	4.3	27.0	35.0	42.0	18.0	210.0	534.7	814.0	51.0	865.0	1,399.7	147.7
1925	28.0	33.9	9.4	1.8	11.0	9.0	15.0	6.0	74.0	188.1	403.8	25.0	428.8	616.9	65.1
1926	45.0	50.0	28.6	14.4	26.0	33.0	32.0	13.0	156.0	398.0	619.5	39.0	[illegible]	1,056.5	111.5
1927	41.0	61.7	24.8	2.7	23.0	27.0	29.0	12.0	143.0	364.2	792.0	45.0	837.0	1,201.2	[illegible]
1928	33.0	60.2	[illegible]	5.6	16.0	17.0	9.6	10.0	117.0	283.9	386.8	24.0	410.8	694.7	73.3
1929	40.0	49.0	21.6	6.0	20.0	25.0	23.0	11.0	128.0	323.6	587.6	37.0	624.6	948.2	100.1
1930	44.0	49.0	17.6	6.0	17.0	20.0	24.0	10.0	119.0	303.6	432.5	27.0	459.5	763.1	80.5
1931	[illegible]	30.0	10.4	6.0	12.0	11.0	26.1	6.0	113.0	237.5	311.0	19.0	330.0	567.5	[illegible]
1932	53.0	67.0	28.2	8.0	25.0	53.0	35.0	15.0	170.0	434.2	848.6	53.0	901.6	1,335.8	141.0
1933	30.0	29.0	11.7	4.5	13.0	12.0	14.8	6.0	79.0	200.0	499.3	31.0	530.3	730.3	77.1
1934	16.0	19.0	9.0	3.4	9.8	9.0	8.6	3.7	52.0	130.5	179.7	11.0	190.7	321.2	33.9
1935	42.0	51.0	19.0	6.0	17.3	21.0	32.4	12.4	124.0	325.1	481.9	30.0	511.9	837.0	88.3
Mean										346.2			601.4	947.6	100.0

[1] Includes estimate of irrigation use above gaging station based on 1936 acreages and consumptive use figures, amounting to 70,000 acre-feet annually.

The estimates for the annual run-off of the eastern and western streams and the combined run-off for the northern unit are given in table 198. This shows a mean annual water production, 1890 1935, for the northern unit of the Middle section, New Mexico, of 947,600 acre-feet.

In the estimates for the southern unit of the Middle section no segregation was made with respect to eastern and western streams. The run-off of this unit is very much less than that of the northern unit and there appears to be less difference between the characteristics of eastern and western streams. Available stream flow records are as follows:

Santa Fe Creek above upper reservoir near Santa Fe, 22 square miles, 1913-35.

Arroyo Hondo near Santa Fe, 14 square miles, 1913 22.

Rio Jemez near San Ysidro, 854 square miles, 1924, 1925

Bluewater Creek near Bluewater, 235 square miles, 1913 19, 1921 35.

San Jose River near Suwanee, 2,765 square miles, 1913-17.

Rio Puerco at Rio Puerco, 4,795 square miles, 1913 25, 1927, 1934, 1935.

Bluewater Creek joins the San Jose River near the town of Grants, and San Jose River is tributary to the Rio Puerco above the Rio Puerco gaging station. Contributing areas of unmeasured run-off include Galisteo and Tijeras Creeks, Rio Salado, and minor streams, totaling 2,387 square miles.

Estimates for the missing years in the period 1913 to 1935 were made for Rio Puerco using an established curve of relation to the run-off of Rio Chama near Chamita and similarly for Arroyo Hondo by reference

to the run-off of Santa Fe Creek near Santa Fe. Because of the very short record on Rio Jemez, its area was included with that of the unmeasured streams.

Above the Rio Puerco station at Rio Puerco water is used for irrigation, and correction was made for this in the water production estimates by adding an estimate of the irrigation consumption to the flow as measured at Rio Puerco. The survey of irrigated areas made in 1936 under the Rio Grande joint investigation showed areas in the Rio Puerco drainage above Rio Puerco station which were grouped in four units as follows: The Cuba unit on the upper Rio Puerco, 2,900 acres; the Cabezon unit on the upper Rio Puerco and Chico Arroyo, 2,600 acres; the Bluewater unit on Bluewater Creek, 13,500 acres; and the San Jose unit on San Jose River, 6,800 acres. The irrigation consumption in these units was determined by adjusting an estimate based upon a unit consumption of 3 acre-feet per acre to an estimate of the run-off in the irrigation season, March to October, above diversions. If this run-off was greater than the total consumption given by a unit use of 3 acre-feet per acre, the total consumption so derived was taken as the value to be used. If the run-off was less, the total consumption was taken as 90 percent of the run-off. To estimate the annual irrigation season run-off above diversions in each unit, the areas of contributing watershed were determined and the mean run-off, 1913 to 1935, computed from assumed values for the run-off per square mile. This mean was made to be consistent with the corresponding mean at the gaging station below the unit. Proportional distribution of the run-off by years was made by reference to the Bluewater record for run-off to the Bluewater and San Jose units and to an upper Rio Puerco record derived by subtracting the Suwanee station flow from that at the Rio Puerco station, for run-off to the Cuba and Cabezon units. Missing flows at the Suwanee station were estimated at 15 percent of those at Rio Puerco. The annual corrections to the Rio Puerco record for upstream irrigation, thus derived, are included in the 1913–35 figures given for the Rio Puerco in table 199.

The run-off of unmeasured streams in the southern unit was estimated by a comparison of their individual drainage characteristics to those of measured streams and the mean annual run-off per square mile of the latter, to derive the mean annual run-off 1913–35 for the total of the unmeasured group. Annual estimates for the latter for this period were derived from the relation, annual to mean, as shown both by the measured streams of the unit and by Rio Chama at Chamita in the same period, using the mean of the values given by these two comparisons.

In the absence of any more representative index, the annual run-off of all streams in the southern unit for

TABLE 199.—*Mountain run-off to southern unit, middle section, Rio Grande Basin, New Mexico*

[Estimated natural run-off at foothill line of valleys, Otowi Bridge to San Marcial]

[Drainage area 8,072 square miles. Unit 1,000 acre-feet]

Year	Santa Fe Creek near Santa Fe, 22 square miles	Arroyo Hondo near Santa Fe, 14 square miles	Rio Puerco at Rio Puerco, 4,795 square miles [1]	Unmeasured streams, 3,241 square miles	Total	Percent of mean
[illegible]					[illegible]	[illegible]
[illegible]					818.0	212.5
1892					600.0	[illegible]
1893					[illegible]	67.5
1894					120.0	[illegible]
[illegible]					440.0	[illegible]
1896					125.0	[illegible]
1897					710.0	[illegible]
1898					185.0	48.1
[illegible]					148.0	38.4
[illegible]					102.0	26.5
[illegible]					188.0	48.8
[illegible]					72.0	[illegible]
1903					602.0	[illegible]
[illegible]					168.0	[illegible]
1905					620.0	[illegible]
1906					630.0	163.6
1907					855.0	[illegible]
[illegible]					270.0	70.1
1909					560.0	145.5
1910					[illegible]	76.6
1911					625.0	162.4
1912					[illegible]	160.5
1913	5.5	0.3	48.6	117.0	171.4	44.5
1914	8.8	.6	162.6	275.0	447.0	116.1
1915	12.5	2.2	295.9	448.0	[illegible]	197.1
[illegible]	13.3	2.3	221.1	435.0	671.7	174.5
1917	2.6	.1	42.2	155.0	[illegible]	[illegible]
1918	4.9	.2	44.2	107.0	[illegible]	40.6
[illegible]	19.0	1.4	234.8	[illegible]	[illegible]	[illegible]
[illegible]	7.0	.1	91.5	277.0	375.6	97.6
[illegible]	18.3	.6	90.8	204.0	313.7	[illegible]
[illegible]	3.5	.1	6.7	[illegible]	100.3	26.1
[illegible]	5.2	.3	30.6	153.0	189.1	[illegible]
[illegible]	10.9	[illegible]	57.2	[illegible]	308.8	[illegible]
[illegible]	2.1	.1	43.5	122.0	167.7	[illegible]
[illegible]	9.6	.6	188.7	315.0	513.9	133.5
[illegible]	4.6	[illegible]	213.0	374.0	591.8	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	119.0	167.0	43.4
1929	8.8	[illegible]	137.6	260.0	407.0	105.7
[illegible]	[illegible]	.3	71.1	158.0	234.8	[illegible]
[illegible]	7.8	.5	[illegible]	84.0	112.8	29.3
[illegible]	6.9	.4	[illegible]	[illegible]	760.4	[illegible]
[illegible]	2.7	[illegible]	61.2	[illegible]	207.0	[illegible]
[illegible]	1.9	[illegible]	[illegible]	104.0	[illegible]	48.5
[illegible]	[illegible]	[illegible]	152.9	246.0	[illegible]	105.4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[1] Corrected for upstream irrigation.

1890 to 1912 was estimated by reference to the gain in the Rio Grande between the Lobatos and Otowi Bridge stations. Between Otowi Bridge and San Marcial there is the extensive irrigation use of the Middle Valley so that this section of the river was not suitable for the above reference. The estimated total annual run-offs 1890–1935 for the southern unit of the Middle section are given in table 199. This indicates a mean annual water production for this unit of 385,000 acre-feet. The figures for the combined run-off of the northern and southern units which is the total run-off for the Middle section, are given in table 202. This shows a mean annual run-off for the Middle section of 1,332,600 acre-feet.

Water Production in the Elephant Butte-Fort Quitman Section, New Mexico, Texas, and Mexico

This is the run-off from the drainage area of the Rio Grande between San Marcial and Fort Quitman, totaling 6,868 square miles and divided as follows:

	Square Miles
San Marcial to Elephant Butte	1, 747
Elephant Butte to Leasburg	2, 163
Leasburg to El Paso	1, 327
El Paso to Fort Quitman	1, 631
Total	6, 868

There are practically no permanent streams entering the Rio Grande in this section. The arroyos which produce most of the run-off as the result of intermittent summer storms are largely tributary from the west between San Marcial and Mesilla Valley. Two streams, Alamosa and Las Palomas Rivers, have a fairly constant spring-fed flow but this is all used in irrigation above the Rio Grande, so that only the arroyo flood flows reach the latter. The only available tributary run-off records are as follows:

Alamosa River near Monticello, 385 square miles, 1931–36.

Las Palomas River near Las Palomas, 190 square miles, 1931 (partial).

With this almost complete lack of run-off records in this section, the most feasible method of estimating the run-off appeared to be that of isolating the Rio Grande gains between upper and lower points, attributable to arroyo inflow. The valley agricultural area in the Elephant Butte-Fort Quitman section is primarily dependent upon water released, as required, from Elephant Butte Reservoir. No dependence is placed upon arroyo inflow and little of it is diverted to the land. Moreover, since the arroyo flow occurs as flash floods carrying large quantities of silt and debris, canal headings are frequently closed to avoid it. This situation makes it possible to estimate the quantity of side inflow between two river points by a process of elimination where detail records are available of river discharge, diversions, and return flows. Such records are available for that portion of the section between Elephant Butte and El Paso. A detail study involving the plotting of daily hydrographs and comparing of daily records was, therefore, entered into to derive the side inflow to two units, Elephant Butte to Leasburg, and Leasburg to El Paso. The following records, complete for the period 1924 to 1936, inclusive, were utilized. Except for the Rio Grande at El Paso record furnished by the International Boundary Commission, these are records compiled and furnished by the Bureau of Reclamation.

Rio Grande below Elephant Butte Dam.
Rio Grande at Percha Dam.
Rio Grande at Leasburg.
Rio Grande at El Paso (Courchesne).
Arcy canal at Percha diversion.
Leasburg canal at Leasburg diversion.
East side canal at Mesilla diversion.
West side canal at Mesilla diversion.
Waste to river in Rincon division.
Waste to river in Leasburg division.
Waste to river in Mesilla division.
Discharge of drains in Rincon Valley.
Discharge of drains in Mesilla Valley.

The daily gains in each unit were derived by comparing the upper and lower river discharge, making due allowance for time lag and intervening diversions, waste and drainage return. The river hydrographs were then inspected to determine whether or not the gains thus shown were due to side inflow or to other causes such as lag in release of channel storage, increase in release of ground water storage following a reduction in flow at the upper river station, discrepancies resulting from the adopted time lag, or merely inaccuracies in records. Gains obviously due to these latter causes were eliminated and arbitrary corrections based on comparison of records, rate of increase and decrease, etc., applied where these conditions were combined with side inflow. Except in two or three unusual years, only the period April to October was considered. In a number of months of this period, no side inflow was found in many years. This period practically covers the entire season of arroyo flow as well as the normal irrigation season, although some water is used in all months except January. Frequently in the months preceding or following the period chosen, Elephant Butte Reservoir releases are quite irregular and this

TABLE 200.—*Estimated tributary inflow, Elephant Butte to Leasburg, 1924–36*

[Drainage area 2,163 square miles. Unit, 1,000 acre-feet]

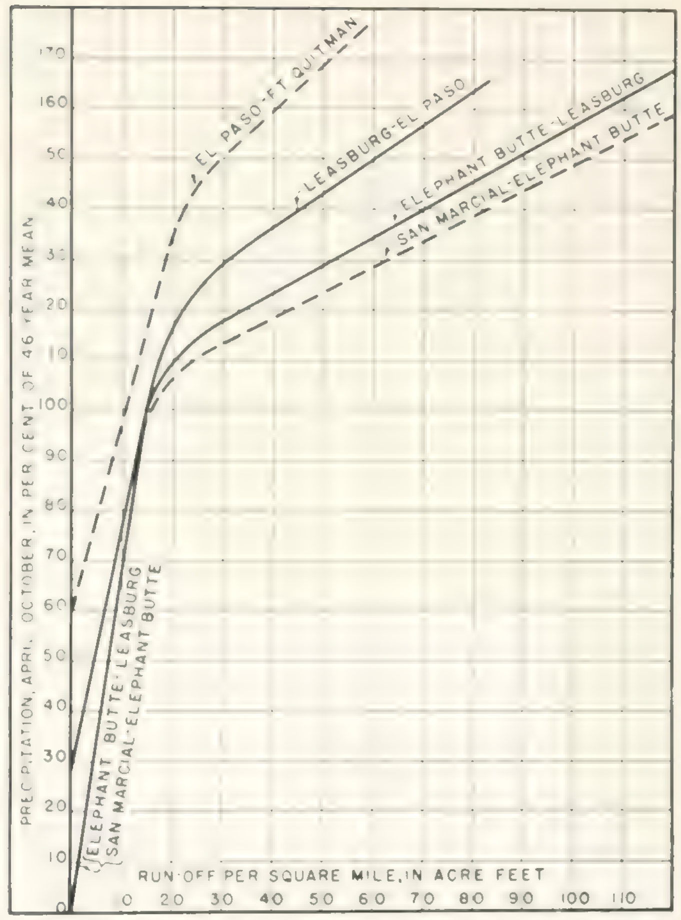
Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1924				6.5	0.6	0.9	8.7	6.3	0	0.3			23.3
1925				0	0	0	16.5	16.3	52.5	.2			85.5
1926			4.1	9.9	39.0	2.4	18.1	8.4	3.5	0			85.4
1927		0.9	0	6.7	1.4	3.5	8.9	6.3	11.2	0			38.9
1928		.3	2.5	15.4	11.3	8.7	13.4	25.1	10.7	3.8	1.3		92.5
1929				2.2	4.0	3.5	20.6	46.2	11.0	11.9			99.4
1930				5.0	2.1	2.4	8.9	15.3	1.0	.9			[illegible]
1931				4.1	.2	1.1	3.5	13.6	3.9	.4			26.8
1932				1.1	1.8	.8	2.8	7.0	9.0	8.5			31.0
1933				.7	1.6	9.0	11.8	10.0	5.5	1.4			40.0
1934				.1	2.1	.3	1.8	10.2	2.6	1.1			[illegible]
1935				.8	1.4	0	.9	18.6	25.2	.1			47.0
1936	0	0	.8	.5	1.4	.3	4.7	7.2	2.2	.2	0	0	[illegible]
Mean	[illegible]	.1	.6	4.1	5.1	2.5	9.3	14.7	10.6	2.2	.1	0	49.3

irregularity makes it very difficult to isolate possible side inflow.

The tributary inflow, by months, in the period 1924 to 1936, as derived by this study, is given for the Elephant Butte-Leasburg unit in table 200 and for the Leasburg El Paso unit in table 201. A mean annual side inflow in this period of 49,300 acre-foot is indicated for the upper unit and 32,400 acre-feet for the lower unit.

As a basis for extending the estimates of tributary inflow to cover the 46-year period 1890–1936 in order to provide some comparison with the water production estimates of the upper sections, the precipitation data for stations within or near each unit appeared to offer the only feasible approach. The stations used for the Elephant Butte-Leasburg unit were Elephant Butte, Hillsboro, Kingston, Garfield, Lake Valley, and Jornado experimental range; and for the Leasburg-El Paso unit, Agricultural College, Cambray, Newman, Lanark, and El Paso. The period of the record at these stations is shown on plate 2. Missing records back to 1890 were supplied by reference to the relation between all stations for their periods of record. In each unit estimates of tributary inflow for the years 1890 to 1923 were made by means of curves drawn to show the relation between the sum of the April-October precipitation at all of the stations of the unit and the corresponding tributary inflow. The annual tributary inflows or run-offs thus estimated, 1890–1923, and as derived by the study previously outlined for the years 1924–36, are shown in table 202.

To complete the estimates of tributary inflow to the Elephant Butte-Fort Quitman section two units remained San Marcial-Elephant Butte and El Paso-Fort Quitman. From the precipitation-run-off data used in extending the tributary inflow estimates for the Elephant Butte-Leasburg and Leasburg-El Paso units, curves were developed to show the relation between April-October precipitation expressed as a percent of the 46-year mean and the run-off in acre-feet per square mile, using the total drainage area of each unit. These curves for the Elephant Butte-Leasburg and Leasburg-El Paso units are shown on figure 44. From the position of these curves, similar ones to represent the San Marcial-Elephant Butte and El Paso-Fort Quitman units were drawn to correspond as nearly as might be estimated with known general relations and probable run-off characteristics. These latter curves, shown dotted on figure 44, were then entered with the April-October precipitation in percent of the 46-year mean to derive the annual April-October run-offs for each unit. Stations for which the precipitation records were used were Rosedale, San Marcial, Chloride Ranger Station, Glorietta Ranch, and Elephant Butte in the San Marcial-Elephant Butte unit and El Paso and Clint in the El Paso-Fort Quitman unit.



[illegible]

The annual tributary inflows or run-offs, 1890 1936, thus derived for these two units are shown in table 202. It is to be noted that this method of extension of the records by reference to precipitation cannot be expected to yield a high degree of accuracy in a region such as the Elephant Butte-Fort Quitman section where the erratic occurrence of rainfall is an outstanding characteristic. However, the complete lack of run-off data leaves no practicable alternative method. The study, described in the section of this report on water supply, to deduce the Rio Grande flow at San Marcial from Elephant Butte Reservoir data, clearly indicates the uncertainties involved and the impracticability of applying this method to a derivation of the tributary inflow to Elephant Butte Reservoir. During 1936 an attempt was made to measure and estimate the arroyo inflow to Elephant Butte Reservoir, but provision for satisfactory conditions to insure reliable estimates was not possible with the time and funds available. The May-October inflow so estimated for the western arroyos was only about 1,000 acre-feet, although the 1936 April-October tributary inflow to the San Marcial-Elephant Butte unit as derived by the study herein was 15,000 acre-feet exclusive of the flow of Alamosa

TABLE 201.—*Estimated tributary inflow Leasburg to El Paso* [1]

[Drainage area 1,327 square miles. Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1921			1.2	7.0	11.4	10.4	18.4	1.9	[illegible]	[illegible]			[illegible]
1922				1.1	[illegible]	7.3	14.6	20.6	[illegible]				[illegible]
192[illegible]			[illegible]	9.4	.1	6.7	15.2	5.0	11.3	.3			[illegible]
1927				.3	3.0	1.2	4.1	6.9	[illegible]	3.7			[illegible]
1928		3.4	[illegible]	4.6	9.2	2.2	[illegible]	4.6	[illegible]	[illegible]			[illegible]
1929			3.6	12.9	16.8	.7	[illegible]	9.8		.7			[illegible]
1930				1.3	3.5	1.8	6.8	2.8	1.9	3.2			[illegible]
1931				[illegible]	2.0	.6	4.8	8.7	3.2	.8			[illegible]
1932				[illegible]	7.6	2.9	[illegible]	1.1	2.9	.3			[illegible]
1933				[illegible]	2.1	[illegible]	1.0	4.5	1.9	.6			[illegible]
1934			.1	.3	.1	.5	.6	1.1	.8	.3			[illegible]
1935				.3	.2	.7	2.1	8.7	1.2	.2			[illegible]
1936	0	.3	0	.4	1.1	.2	.5	1.6	.7	[illegible]	0	[illegible]	[illegible]
Mean		.3	1.4	4.5	5.2	2.9	6.6	[illegible]	[illegible]	1.1	[illegible]	[illegible]	[illegible]

[1] To Courchesne gaging station.

TABLE 202.—*Mountain run-off to Middle and Elephant Butte-Fort Quitman sections, Rio Grande Basin, N. Mex. and Tex.*

[Estimated natural run-off at foothill line of valleys, Colorado State line to Fort Quitman, Tex.]

[Drainage area 19,581 square miles. Unit, 1,000 acre-feet]

Year	Middle section			Elephant Butte-Fort Quitman section					
	Northern unit, 4,041 square miles	Southern unit, 8,672 square miles	Total, 12,713 square miles	San Marcial-Elephant Butte unit,[1] 1,747 square miles	Elephant Butte-Leasburg unit, 2,163 square miles	Leasburg-El Paso unit, 1,327 square miles	El Paso-Fort Quitman unit, 1,631 square miles	Total, 6,868 square miles	New Mexico production, columns (3) to (6), inclusive
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1890	1,240.0	640.0	1,850.0	22	33	19	23	97	1,924.0
1891	1,510.0	818.0	2,328.0	24	18	3	0	[illegible]	2,373.0
1892	1,230.0	600.0	1,830.0	15	12	1	0	28	1,858.0
1893	790.0	260.0	1,050.0	44	170	77	48	339	1,341.0
1894	504.0	120.0	624.0	18	16	6	0	40	664.0
1895	1,010.0	440.0	1,450.0	81	69	34	28	212	1,634.0
1896	530.0	125.0	655.0	121	[illegible]	51	28	276	903.0
1897	1,370.0	710.0	2,080.0	153	266	90	105	614	2,589.0
1898	650.0	185.0	835.0	109	95	21	3	228	1,060.0
1899	590.0	148.0	738.0	23	20	19	16	78	800.0
1900	450.0	102.0	552.0	18	21	18	21	78	609.0
1901	665.0	188.0	853.0	17	29	49	16	111	948.0
1902	380.0	72.0	452.0	24	37	20	31	112	533.0
1903	1,215.0	602.0	1,817.0	24	31	67	53	175	1,939.0
1904	627.0	168.0	795.0	33	135	68	72	308	1,033.0
1905	1,240.0	620.0	1,860.0	78	102	39	64	283	2,079.0
1906	1,260.0	630.0	1,890.0	23	33	17	38	111	1,963.0
1907	1,216.0	855.0	2,071.0	186	53	21	24	284	2,331.0
1908	1,026.0	270.0	1,296.0	25	27	14	13	79	1,362.0
1909	1,223.0	560.0	1,783.0	21	21	10	0	52	1,835.0
1910	820.0	295.0	1,115.0	26	18	7	0	51	1,166.0
1911	1,212.4	625.0	1,837.4	194	55	23	33	305	2,109.4
1912	1,186.1	618.0	1,804.1	90	128	103	32	353	2,125.1
1913	576.0	171.4	747.4	21	34	13	0	68	815.4
1914	940.0	447.0	1,387.0	105	172	70	67	414	1,734.0
1915	1,285.2	758.6	2,043.8	163	31	14	21	229	2,251.8
1916	1,565.1	671.7	2,236.8	143	149	22	15	329	2,550.8
1917	972.1	199.9	1,172.0	20	15	14	15	64	1,221.0
1918	655.8	156.3	812.1	24	33	16	11	84	885.1
1919	1,137.8	640.2	1,778.0	56	44	35	32	167	1,913.0
1920	1,363.5	375.6	1,739.1	21	[illegible]	19	1	81	1,819.1
1921	1,112.4	313.7	1,426.1	37	29	19	11	96	1,511.1
1922	635.9	100.3	736.2	16	18	8	0	42	778.2
1923	927.2	189.1	1,116.3	22	30	14	7	73	1,182.3
1924	1,399.7	308.8	1,708.5	20	23	62	11	116	1,813.5
1925	616.9	167.7	784.6	24	86	68	[illegible]	191	962.6
1926	1,056.5	513.9	1,570.4	36	85	54	28	203	1,745.4
1927	1,201.2	591.8	1,793.0	28	39	26	5	98	1,886.0
1928	694.7	167.0	861.7	25	92	41	24	182	1,019.7
1929	948.2	407.0	1,355.2	116	99	52	27	294	1,622.2
1930	763.1	234.8	997.9	24	36	21	5	86	1,078.9
1931	567.5	112.8	680.3	60	27	26	34	147	793.3
1932	1,335.8	760.4	2,096.2	26	31	22	38	117	2,175.2
1933	730.3	207.0	937.3	26	40	27	11	104	1,030.3
1934	321.2	186.9	508.1	20	18	4	0	42	550.1
1935	837.0	405.8	1,242.8	24	47	13	8	92	1,326.8
46-year mean	947.6	385.0	1,332.6	53.0	58.5	30.8	22.5	164.8	1,474.9
46-year median				25.0	31.0	21.0	[illegible]	[illegible]	
1936				23	17	[illegible]	18	[illegible]	

[1] Includes flow of Alamosa River which would not be inflow to Elephant Butte Reservoir because of irrigation use.

River, which it may be assumed was all used in irrigation.

The erratic character of the run-off in the Elephant Butte-Fort Quitman section and the difficulties involved in estimating it are well illustrated by the wide divergence between the 46-year means and the 46-year medians for the units of this section as shown at the bottom of table 202. For instance, the total mean annual run-off for the section, influenced largely by a few erratic years of high run-off, is 164,800 acre-feet, although as indicated by the median, the run-off in 23 of the 46 years was 111,000 acre-feet or less.

If the estimated mean annual run-off of 22,500 acre-feet in the El Paso-Fort Quitman unit is divided to Texas and Chihuahua, Mexico, in direct proportion to their respective drainage areas tributary to the Rio Grande in this unit, the Texas run-off is 11,000 acre-feet and that of Chihuahua 11,500 acre-feet.

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PART II

GROUND WATER RESOURCES

Report of the United States Geological Survey

CONTENTS

Section 1. Geology and Ground Water Conditions

Section 2. Ground Water in the San Luis Valley, Colorado

Section 3. Ground Water in the Middle Rio Grande Valley, New Mexico

PART II

SECTION 1. GEOLOGY AND GROUND-WATER CONDITIONS OF THE RIO GRANDE DEPRESSION IN COLORADO AND NEW MEXICO[1]

General Statement

The investigation of the geology and ground-water conditions in the Rio Grande Valley was made as a part of the Rio Grande Joint Investigation under the auspices of the Water Resources Committee of the National Resources Committee. The investigation was made by the Ground Water Division of the United States Geological Survey under the direction of C. V. Theis and under general supervision of O. E. Meinzer, who is in charge of the Division. David G. Thompson, senior geologist in the Ground Water Division, was in the field from March 12 to May 3, 1937, and contributed greatly in organizing the work. Sections 1, 2, and 3 of part II were prepared on the basis of this investigation.

The Rio Grande flows from the heights of the San Juan Mountains in Colorado to the sea through a series of structural basins that were formed chiefly by faulting and other deformation of the older rocks and subsequent filling with sedimentary and volcanic deposits. This series of basins forms a structural depression that is referred to in this paper as the Rio Grande depression. The basins differ from one another in their physical characters, their present social and economic standards, the order in which they have been successively occupied by different races of men, and the completeness of their occupation. Therefore each basin is a geographic unit, not only in its physical aspect but also in its historical development. The impact of the environment and the reaction induced by successive incursions of groups differing radically in race, language, and customs have led to social and political differences as great as the separation in space and in topography.

The physical rather than the social or historical features of the several basins of the Rio Grande in Colorado and New Mexico are here set forth. The several parts of the region traversed by the Rio Grande, in spite of their differences, have many similarities, which can be traced back to a common geologic history. This history is here summarized to account for the striking differences in the topographic forms of the several basins and in their equally important hydrologic conditions.

[1] By Kirk Bryan, senior geologist in the U. S. Geological Survey and associate professor of geology in Harvard University.

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Sources of Data

Knowledge of the geology and geomorphology of New Mexico, particularly the north-central portion, has been gained over a long period by many observers. A general description of the successive valleys was first made by Lee [2] in 1907, and his description has been drawn on in this paper. The general stratigraphy and structure of the pre-Tertiary rocks was presented by Darton [3] in 1928 in a comprehensive paper that contains an extensive bibliography of earlier literature. For the area below the Socorro quadrangle, Harley's work on Sierra County [4] and the brilliant monograph by Dunham [5] have been useful.

The writer began work in the area in 1909, and at different times in 1916 and later years he made reconnaissances. In 1925, 1927, 1928, and 1929 he studied various problems under the auspices of the United States Geological Survey and other agencies. Since 1931, with the help of Harvard students and largely aided by different funds of Harvard University, he has been engaged in a general attack on the Tertiary geology and the geomorphology of the area. Dr. H. T. U. Smith has completed a study of the Abiquiu quadrangle. Prof. R. E. Nichols has investigated about 70 miles of the San José Valley from Grants to the Rio Puerco. Franklin T. McCann worked with the writer near Cuba, N. Mex., and again at the north end of the Ceja del Rio Puerco. Joseph E. Upson and Charles S. Denny are still engaged respectively in studies of the east side of the San Luis Valley and of the basin just north of the San Acacia constriction. The writer studied the Socorro quadrangle in 1925 and again in 1931. With J. E. Upson he completed a study of the Santo Domingo area in 1934. A. N. Dangerfield has begun a study of the Mesilla Valley. Each of these men and the writer have been assisted in the field by students of Harvard and other colleges. The enthusiasm and sacrifices of these volunteers would deserve separate mention if space permitted. The

[2] Lee, W. T., Water Resources of the Rio Grande Valley in New Mexico: U. S. Geol. Survey Water-Supply Paper 188, 59 pp., 1907.

[3] Darton, N. H., "Red Beds" and associated formations in New Mexico, with an outline of the geology of the State: U. S. Geol. Survey Bull. 794, 356 pp., 1928.

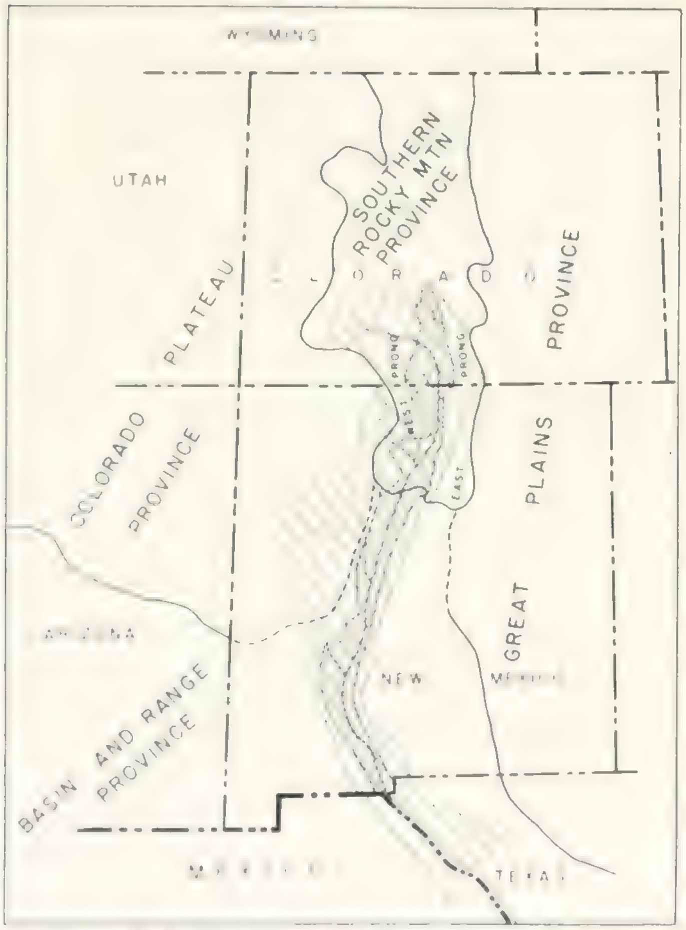
[4] Harley, G. F., The geology and ore deposits of Sierra County, N. Mex.: New Mexico School of Mines, Bur. Mines and Mineral Resources, Bull. 10, 220 pp., 1934.

[5] Dunham, K. C., The geology of the Organ Mountains, with an account of the geology and mineral resources of Dona Ana County, N. Mex., New Mexico School of Mines, Bur. Mines and Mineral Resources Bull. 11, 272 pp., 1935 (1936).

studies recounted above are being prepared for publication and, although several papers are in press, only preliminary announcements and a few papers had appeared in print by the winter of 1937. The writer expresses his thanks to these coworkers and assistants for the use of material here included and for many pleasant hours in the field.

Broad Relations of the Rio Grande Drainage Area

The drainage area of the Rio Grande includes parts of Colorado, New Mexico, Texas, and Mexico, with diverse topographic characteristics. The region is commonly divided into provinces of somewhat homogeneous characteristics (fig. 45). The Southern Rocky Mountains of Colorado extend southward into New Mexico as two prongs. The Sangre de Cristo Mountains form the eastern prong and end at Glorieta. The Conejos and Jemez Mountains form the less unified western prong and end at the pueblo town of Jemez. Here, at approximately 35°30′ north latitude, the Colorado Plateau province, the Basin and Range province, and the Great Plains province border in a relatively small area. The Rio Grande, rising in the high San Juan Mountains, flows eastward through deep canyons as a clear mountain stream into the San Luis Valley. This broad open area of plains, with a general altitude above 7,500 feet, is obviously a depression in the mountain belt merely modified by the entrance of the river. It is the northern portion of the Rio Grande depression, which, beginning at Poncha Pass, about 50 miles north of the entrance of the Rio Grande, extends southward between the two prongs of the Rocky Mountains for nearly 200 miles. This part of the depression is diversified by hills, volcanic peaks, and lava-capped plateaus and is generally included in the Southern Rocky Mountain province. However, structurally it is continuous southward, with an offset to the west of about 30 miles, with a series of contiguous basins that form part of the Basin and Range province.



[illegible]

Within the Basin and Range province, as far as El Paso, the course of the Rio Grande lies generally within the basins and is roughly parallel to the ranges. At El Paso there is an abrupt change to a southeasterly direction, across the basins and ranges, in the area known as the Big Bend. Thence the river continues to flow southeastward down the slope of the coastal plain. The abrupt change in course at El Paso has led to various suggestions that the present Rio Grande has been formed by two rivers. According to these suggestions, the upper river once flowed southward in the broad basins of northern Mexico, where it evaporated, but it was captured by the headward erosion of the lower river.

The lower river, emerging from the series of canyons below Fort Quitman and rejuvenated by the influx of the Pecos and several large tributaries from the Mexican side, is a broad stream of low gradient, slightly incised in extensive mesquite-covered plains which become lower and lower. The smooth plains of the delta begin about 80 miles from its mouth and are irrigated in the subtropical Brownsville area. The isolated valleys of the upper river area are indeed remote from this "Winter Garden", which is in communication by sea with the whole world.

The Rio Grande above Fort Quitman is a complex stream in that it flows from basin to basin through canyons or other restrictions. It may be roughly likened to a stream flowing from one sand-filled tub to another through narrow troughs. Each tub differs in size and shape from the others and contains sand of a different quality. In these tubs water is lost by

[illegible]

evaporation and is also gained by local rainfall on the sand. The troughs also differ in shape and length, and in some of them there is a gain of water.

The basins consist of broad plains between mountains. Only in the lower part of the San Luis Valley does the river run essentially at the grade of the plains. In the other basins it is incised from about 250 to 500 feet and flows in an inner valley, or trench, that has a flat floor, 1 to 4 miles in width. These inner valleys contain the irrigated lands, meadows, and cottonwood groves on which the successive civilizations of the Pueblo Indians, the Spaniards, and the present American inhabitants have depended. To them the inner valley is the important feature, and names have been given to its wider portions and intervening contractions. In the following description the names of the inner valleys, or trenches, are used also to designate the structural basins in which they lie.

The several parts of the depression differ in their altitude above the river and in the degree of dissection. Some parts are smooth plains, others are a maze of steep-walled gulches, and still others are basalt-covered plateaus. All these areas, except the flood plain of the Rio Grande within the inner valleys and the flat floors of some of the principal tributary streams, have a deep water table and low run-off. The Santa Fe formation is the principal body of sedimentary deposits in the structural basins which in this paper are collectively called the Rio Grande depression. It is somewhat permeable and produces sandy soils that promote infiltration of rain. Similarly, the widespread cover of gravel, which was deposited in several successive Pleistocene stages, is open and permeable. The basalt-covered areas are very conducive to surface infiltration, and large parts of the basalt-covered plains have no surface run-off, even in the most severe rain storms. A further characteristic of these surfaces is the presence of wind-borne or wind-laid soil over large areas. The sandy dissected slopes and the sandy beds of streams furnish at present and have furnished in the recent geologic past large supplies of sand to the wind. This material has been deposited on flat surfaces of gentle grade and forms a permeable soil that promotes infiltration and decreases run-off.

The principal characteristic of these areas which inhibits infiltration is the presence of caliche. This deposit of calcium carbonate forms crusts ranging from a mere impregnation of the soil to a layer of compact limestone 2 to 15 feet thick. This layer lies from a few inches to a few feet below the surface over large areas. It forms a barrier to the infiltration of rainfall that is effective in proportion to its thickness and the perfection with which it has been made and preserved.

The mountains and highlands that border the Rio Grande depression differ from the depression in many ways as regards water supply. In the first place, they generally, though not everywhere, stand at higher altitudes and hence receive a greater precipitation. Their water supply is not only greater but also more continuous, because much of the winter precipitation occurs as snow and hence runs off with relative slowness as the snow melts. Furthermore, these areas have a greater vegetative cover, which tends to delay the run-off.

In the second place, the steeper slopes and relatively impervious character of the rocks of the mountains and highlands promotes rapid run-off in contrast to the characteristics of the basins just set forth. Thus the greatest floods come from these highland areas, even though the only perennial streams of the region also run from them. The rocks of the highland areas are also variable in their permeability. On the whole, infiltration into them is moderate in quantity and the ground-water reservoirs are small, but there are notable exceptions. Thus, as will be brought out more at length, the great limestone plateau of the Sandia Mountains is fissured and cavernous and therefore forms a considerable ground-water reservoir to feed the springs at the east base of the mountains.

The importance of these major differences with respect to water supply is rather obvious, but their effects on the relative size of stream valleys and the relative efficiency of individual streams is likely to be overlooked.

Outline of the Structural Basins and Their Inner Valleys

San Luis Valley and Rio Grande Canyon

The first of the structural basins through which the Rio Grande flows is the San Luis Valley of Colorado, which begins at Poncha Pass and ends where shallow canyons in the rocks of the San Luis Hills begin. (See fig. 47.) South from these canyons, the river flows in an open valley, with the hills on the west and broad plains on the east. This area is economically and socially a part of the San Luis Valley, but structurally and in part hydrographically it is distinct. The State Line Bridge, about 6 miles north of the New Mexico line, marks the beginning of the Rio Grande Canyon—a narrow gorge in basalt. From a start as a narrow trench only 50 feet deep, the canyon deepens in the next 50 miles to Embudo, where the basalt-capped walls are 1,200 feet high. This deep canyon and the sage-covered basalt plateau in which it is incised effectively separate the San Luis Valley from the lower valleys, not only physically but also in an economic and social sense. Structurally this part of the depression is not well known, as the great floods of basaltic lava have covered its complexities and have given a surficial unity to an area that is structurally diverse.

Española Valley

In the next 25 miles the river runs through the Española Valley. (See fig. 48.) On the west this valley receives the Chama River and is connected with the Abiquiu area; on the east it receives a number of small streams that connect it with small irrigated valleys at the foot of the Sangre de Cristo Range. Economically the area around Santa Fe is part of this region, but, explained on page 224, Santa Fe Creek and the plains to the south of Santa Fe constitute an area that is hydrologically distinct.

White Rock Canyon

At Buckman begins the White Rock Canyon, known to the Spanish as Caja del Rio. It is a narrow gorge, 20 miles long, between the Sierra de los Valles and the Cerros del Rio.

Santo Domingo Valley

The next valley, marked by the entrance of Santa Fe and Galisteo Creeks from the east, is the comparatively small Santo Domingo Valley, about 20 miles long. (See figs. 48 and 49.) It ends at San Felipe, where there is a short and relatively insignificant constriction of the valley by the basalt plateau of Santa Ana Mesa and the little butte called San Felipe Mesa. The insignificant character of this constriction is out of proportion to the relatively large change in the character of the basin. Here the Rio Grande depression emerges from the Southern Rocky Mountain province into the Basin and Range province, and here the depression as a whole is offset to the west about 20 miles. The Santo Domingo Valley lies in this area of offset but it is related structurally to the basin at the north.

Albuquerque and Belen Valleys

The Albuquerque and Belen Valleys lie in a part of the Rio Grande depression which is 80 miles long and 25 to 35 miles wide with a general trend about 10° west of south. (See fig. 49.) The eastern border of the depression is a continuous belt of narrow but high mountains, named, from north to south, the Sandia, Manzanita, and Manzano Mountains and the Sierra de los Pinos. Canyons have been cut around and between these ranges, and consequently not only their westward slopes but also a considerable part of their eastward slopes drain to the Rio Grande. Each of these canyons affords a pass or means of access to the Estancia Valley and the plains beyond. The waters of the canyons north of the Sandia Mountains enter the valley at Bernalillo. Between the Sandia and Manzanita Mountains is Tijeras Canyon (Canyon de Carnuel), whose waters enter the valley 4 miles south of Albuquerque. Between the Manzanita and Manzano Mountains is Hell Canyon (Canyon del Diablo), whose waters enter the valley near Isleta. Between the Manzano Mountains and the Sierra de los Pinos is Abo Canyon, whose waters enter the valley near Belen. The pass at the south end of the Sierra de los Pinos is less well defined, though adequate for a rough wagon road. The water of this area, passing through the gulch called Agua de Torres, reaches the river at La Joya.

A part of the structural basin occupied by the Albuquerque and Belen Valleys is higher than the adjacent region to the west. The western prong of the Rockies, locally called the Sierra Nacimiento, ends in the Sierrita Mesa. West of this prong the Colorado Plateau province is relatively low. Farther south it comes into contact with the basin along the Ceja del Rio Puerco, a westward-facing escarpment. This escarpment extends southward nearly 60 miles but forms the boundary of the basin for only about 30 miles, or as far as Cerro Colorado. In this 30-mile stretch the surface of the basin, underlain by valley fill, stands 400 to 500 feet higher than the adjacent Colorado Plateau province. From Cerro Colorado the boundary of the basin crosses the broad valley of the Rio Puerco in a vague southwesterly course to the Rio San José. Thence south for 25 miles, to the north end of the Sierra Ladron, the boundary is a well-defined but diversified eastward-facing escarpment of sedimentary rocks capped with basalt. Here the basin narrows toward the south end of the Belen Valley at San Acacia.

The inner valleys known as the Albuquerque and Belen Valleys are separated from each other by a partial constriction at Isleta. This constriction is not a canyon but only a narrow place in the flood plain formed by the outcrop of a layer of basalt. The lower end of the Belen Valley is marked by the entrance from the west of the Rio Puerco, the longest tributary of the Rio Grande within New Mexico, and the Rio Salado, another important tributary.

San Acacia Constriction

The San Acacia constriction, in itself a small feature, marks an important change in the shape and form of the Rio Grande depression. The inner valley narrows and becomes a canyon about [illegible] feet deep and less than half a mile long. The rock walls are of dark-gray andesite, in contrast to the characteristic gravelly bluffs of the valleys to the north and south.

Socorro Valley

The Socorro Valley extends about 38 miles, from San Acacia to San Marcial, and is about 1 to 3 miles wide. (See fig. 50.) From San Acacia to San Antonio the river is near the east side of the valley, and nearly all the irrigated land lies west of the river. From San

Antonio south to San Marcial the river flows nearer the middle of the inner valley, but even here the flood plain on the east side is narrow and discontinuous.

The basin in which this valley lies is complex. In the northern portion it is only 8 to 12 miles wide and lies between mountains on the west, and a highland on the east. South of San Antoñio the plains widen out and the course of the river is southwestward to San Marcial. The great basin called the Jornada del Muerto lies to the east, and plains 6 to 8 miles wide extend westward to the south end of the Magdalena Range.

The marked structural change at San Acacia is obviously connected with this constricted northern portion of the Socorro Valley and with the border basins into which the river flows south of this area.

San Marcial Constriction

The constriction at San Marcial is due to a great basalt flow which forms a cliff southeast of the town and which covers about 140 square miles of the Jornada del Muerto east of this point. According to Lee's theory,[7] the river once ran southward from this point through the broad Jornada del Muerto and thence across La Mesa into Mexico and was later diverted from this course by the lava flow at San Marcial.

Engle Valley

From San Marcial the river still bears somewhat west of south and runs for more than 40 miles in a narrow valley west of the Fra Cristobal Mountains. A dam 250 feet high at Elephant Butte has converted this area into a reservoir.

Elephant Butte Canyon

Beginning a few miles north of the dam site, the river runs in a narrow canyon cut in the rocks of the north end of the Sierra Caballo.

Rincon Valley

From Elephant Butte Canyon the river emerges into a basin that lies on the west side of the Sierra Caballo and extends far south of it. In this basin the river runs in a valley somewhat wider than the Engle Valley for nearly 50 miles. This valley is called the Rincon or Las Palomas Valley, after one or the other of the towns within it. In its lower part the valley turns sharply eastward for a distance of about 12 miles.

Seldon Canyon

The Seldon Canyon, below the Rincon Valley, is about 18 miles long and is wide enough for a railroad and highway. It is somewhat diversified in aspect, as it cuts through rocks of differing hardness. The trend of the canyon is southeastward, and its lower end is directly south of San Marcial. Thus in this series of narrow valleys and constrictions about 100 miles long, the river has accomplished a great bend to the west of more than 20 miles.

Mesilla Valley

The Mesilla Valley has a southeasterly course diagonally across the trend of the Jornada del Muerto and its supposed southern extension, which is called La Mesa. The Mesilla Valley is 50 miles long and about 1 to 4 miles wide. The lower stretch of about 20 miles is essentially parallel to the north-south trend of the Franklin Mountains. The river then turns sharply southeastward into the El Paso Canyon.

El Paso Canyon

The El Paso Canyon is a gorge between the Franklin Mountains and the Cerro Rodadero, also called Cerro de Muleros, cut partly in rock and partly in deformed beds of sand and gravel. This canyon separates the Mesilla Valley from the El Paso Valley and has special importance because here are also the international boundary and one of the principal cities of the region.

El Paso Valley

The El Paso Valley has a southeasterly trend across the Hueco Basin, which, with the Tularosa Basin, to the north, has a north-south trend. The valley is about 90 miles long and ends at Fort Quitman, in a canyon at the south end of the Quitman Range.

Older Rocks of the Highlands and Mountain Ranges

Pre-Cambrian Complex

The oldest rocks of the region are great masses of schist, gneiss, and granite which together form a crystalline complex considered to be of pre-Cambrian age. Near El Paso the complex is overlain by upper Cambrian and Ordovician strata, but farther north the oldest overlying rocks are of Pennsylvanian age. In the southern part of the region the pre-Cambrian age of the complex seems to be well established, but the scattered areas farther north show a less definite age relation. However, the different areas of these rocks, although widely separated and but little studied in detail, appear to have a common antiquity by reason of their high degree of foliation and metamorphism and the marked unconformity between them and the overlying Pennsylvanian rocks.

The schists are of both igneous and sedimentary origin, and there are large thicknesses of quartzite, which in some places is the dominant rock. These metamorphic rocks are intruded by great masses of igneous rock, chiefly granite and granodiorite.

[7] Lee, W. T., Water resources of the Rio Grande Valley in New Mexico and their development: U. S. Geol. Survey Water-Supply Paper 188, p. 23, 1907.

Throughout the geologic history subsequent to their formation these rocks have been resistant to erosion and have formed highlands. From them pebbles have been carried into all the later rocks, and many quartz and quartzite pebbles have been rehandled several times as the later formations have been successively uplifted and eroded. At present these crystalline rocks form large parts of the higher ranges, particularly in northern New Mexico and in Colorado, and they furnish easily identifiable débris to the streams.

Pennsylvanian and Older Paleozoic Rocks

At the beginning of Paleozoic time a sea invaded the area from the south. In this sea the early Paleozoic rocks are laid down as a thin mantle overlying the pre-Cambrian complex. The land surface cut on the older crystalline rocks to the north must have been low, as the deposits in these early seas were mostly shale and limestone. The Bliss sandstone, El Paso, Montoya, and Fusselman limestones, and Percha shale have a total thickness of 460 to 1,350 feet and represent the time from the Upper Cambrian to the Upper Devonian. However, as slight uplift and erosion occurred after the deposition of each formation, the maximum thickness of these beds is not present in any one place. The northerly outcrops of these beds are in the San Andreas and Oscura Mountains and near Chloride. North of this latitude these formations are unknown. The Lake Valley limestone, of Mississippian age, has a maximum thickness of 210 feet. It overlaps the older rocks as a thin wedge extending north to latitude 34°30′, where its last known exposure is in the Sierra Ladron.

The Magdalena group, of Pennsylvanian age, consists largely of limestone with some shale and a variable amount of sandstone and conglomerate at the base. These rocks form a huge plate 900 to as much as 2,500 feet thick, extending from the south to the north so as to overlap the older sedimentary rocks just described and to extend over the crystalline complex northward into Colorado and beyond.

Near El Paso the pre-Pennsylvanian rocks cover considerable parts of some of the smaller ranges. In general these rocks are of little importance either as yielding runoff or as sources of material for later sediments. The Magdalena group is, however, of very large importance. It covers most of the Caballo, San Andreas, Socorro, and Ladron Ranges and forms nearly all of the Sierra de los Pinos-Manzano-Sandia uplift, where it is generally 900 to 1,200 feet thick. It is resistant to erosion under the present climate and forms part of the highest areas, but it furnishes some large blocks and pebbles that are carried by ephemeral streams 10 to 12 miles from the outcrops. The older basin deposits also contain pebbles of this limestone. West of the Franklin Mountains the basin deposits are mostly conglomerates of limestone pebbles, derived in part, however, from the early Paleozoic limestones. On the west flank of the Sangre de Cristo Mountains the basin deposits contain very few limestone pebbles, although there are large outcrop areas of the Magdalena within the range.

Permian Rocks

The Permian rocks consist of the Abo sandstone and the complex assemblage called the Chupadera formation.

The Abo sandstone has a thickness of 600 to 1,000 feet and is a slabby sandstone of strong brown-red color. It is generally resistant to erosion and furnishes characteristic pebbles that occur in the basin deposits of all ages. Its areas of outcrop are generally small, however, and it is relatively unimportant in the formation of the present ranges.

The Chupadera formation varies in character from place to place. Within the Rio Grande drainage area it contains red sandstone and shale, with gypsum beds at the base and limestone with subordinate red shale and gypsum in its upper part. To the north and west the gypsum disappears from the lower member and the limestone from the upper, so that the formation is largely red and gray sandstone and red shale. In the northern part of the area the thickness is generally less than 500 feet, whereas to the south and particularly to the southeast thicknesses of 2,000 to 5,000 feet are known.[8] Both the limestone and the red beds of this formation cover large areas and in many places form high escarpments and plateaus. The limestones are grayer and more porous than those of the Magdalena group, and therefore the pebbles and fragments derived from them are easily recognized. Such fragments are plentiful in the Santa Fe formation east of Socorro and in many recent stream deposits. Red sandstone also occurs as pebbles west of the Joyita Hills and also west of Rosario siding, in the Santo Domingo Valley. The red beds ordinarily disintegrate on weathering into sand and clay having a persistent red color. The flood waters of many streams are colored red by the erosion of these beds and by somewhat similar red coloring matter from the Triassic and Jurassic rocks. Rio Colorado, a tributary of the Rio San José, the Chama River, the upper Rio Galisteo, and many smaller and less well-known streams carry red mud in floods. To what extent the persistent red or pinkish color of the Pliocene deposits is due to redeposition of this red coloring matter remains in doubt, but the Santa Fe formation east of Socorro, with its large content of Permian limestone fragments, doubtless owes its deep-red color to the transfer of fine mud from the red beds of the Chupadera formation.

[8] [illegible]

Triassic Rocks

Within the Rio Grande drainage area the Triassic system is represented mostly by red sandy shale of the Chinle formation, which has a deep-red color and a thickness of 200 to 800 feet. In the Nacimiento uplift and the Chama Basin the Chinle is underlain by a massive gray to white pebbly sandstone called the Poleo sandstone.

Jurassic Rocks

According to the most recently published work,[9] the Jurassic rocks in New Mexico may be divided into the Wingate sandstone and the Morrison formation. The Wingate sandstone lies above the Chinle formation and its equivalents and is referable to the Jurassic only with some doubt. The Morrison formation of these writers includes the Todilto limestone of previous writers and also the sandstone previously called the Navajo sandstone.

The Wingate sandstone is a reddish buff to white massive sandstone diminishing from a thickness of about 300 feet at Thoreau to about 80 feet east of the Rio Grande. This sandstone, together with the gypsum of the overlying Todilto limestone member, usually forms a scarp that may be subordinate to higher cliffs, as in the scarp north of the Chama River.

The basal member of the Morrison formation in New Mexico is the Todilto limestone member, which consists of 50 to 100 feet of gypsum and a thin bed of fresh-water limestone. West of longitude 107° it is overlain by a massive sandstone, which, like the Wingate, is reddish buff to white and which has been called Navajo sandstone in previous reports. Overlying this sandstone, where present, and extending over the northern half of the State, is a series of soft white to brown sandstones, and green, red, and purple shales. The thickness of this upper part of the Morrison ranges from 150 to 900 feet. This sandstone and shale series of the Morrison is resistant to erosion only where protected by the overlying Dakota sandstone. Generally the soft unctuous clays weather to slippery mud that induces landsliding and rapid erosion.

The Wingate sandstone and the sandstones in the Morrison formation generally weather to sand rather than sandstone blocks. The shales of the Morrison yield clay and some sand. The gypsum of the Todilto limestone member increases the quantity of sulphate in the streams.

Cretaceous and Early Tertiary Rocks

Lower Cretaceous rocks are somewhat rare in New Mexico, and generally the Upper Cretaceous directly overlies the Morrison or older rocks. The Upper Cretaceous varies in thickness and characteristically consists of buff sandstones and dark shales. Within the Rio Grande drainage area it includes, in upward succession, the Dakota sandstone, about 80 to 100 feet thick; the Mancos shale, a dark shale, about 900 to 2,000 feet thick; the Mesaverde formation, consisting of massive buff sandstones, shale, and coal and ranging in total thickness from about 500 to 2,500 feet; the Lewis shale, a dark-gray shale, about 80 to 2,000 feet thick; the Pictured Cliffs sandstone, about 50 to 300 feet thick; the Fruitland and Kirtland formations, a heterogeneous sequence of sandstone, coal, and white, gray, and drab shales, ranging in total thickness from about 700 to 1,600 feet; and the buff Ojo Alamo sandstone, about 125 to 400 feet thick, which may be of Tertiary age. Above the Cretaceous rocks are the early Eocene, Puerco and Torrejon formations, consisting largely of gray and dark shale and soft sandstone, reaching a thickness of about 800 feet on the west side of the Sierra Nacimiento. The Galisteo sandstone, probably of Eocene age, crops out near Cerrillos and also on the east and southeast border of the Santo Domingo Valley. It consists of poorly cemented sandstone and conglomerate with red and green clay and ranges from about 1,300 to 3,800 feet in thickness. The Wasatch formation, which crops out largely in the Sierra Nacimiento, includes a basal sandstone, 100 feet or more thick, and sandy shales of variegated color ranging from red and purple to yellow, which reach several hundred feet in thickness.

All the Cretaceous and Eocene beds described in the preceding paragraphs consist of sandstones and shales with an aggregate thickness reaching 16,000 feet, but by reason of local erosion and nondeposition of beds, the ordinary thickness of the whole sequence is nearer 5,000 feet. The common character of the Cretaceous and early Tertiary beds is reflected in their weathering and topography. Generally the sandstones form escarpments, mesas, and cuestas, and the shales form badlands or broad smooth plains. Some of the sandstones are so thin or so friable as to have much the same topographic expression as the shales. Generally the Dakota, the Pictured Cliffs, the Mesaverde, the Ojo Alamo, and the basal sandstones of the Wasatch form conspicuous cliffs. The variations in the thickness of these beds and the sporadic lenses of a similar sandstone that occur in otherwise predominantly shale members afford the chief variations in the topography.

The shales weather to gummy clays that are important hazards to travel in wet weather. The sandstones weather to fine-grained sand. Consequently the streams of areas underlain by these rocks have a large load of fine material and a minimum of gravel. Such gravel as exists consists of iron and lime concretions and pebbles of quartz, quartzite, and chert derived

[9] [illegible] Prof. Paper 183, pp. 30-31, 1936.

from the conglomeratic phases of the sandstones, together with thin plates of the more thoroughly cemented sandstone layers. Fine-grained alluvium, mostly sand but containing much colloidal clay, has accumulated in broad valley flats which are now deeply cut by arroyos. Here originate the heavy loads of detritus carried by the Rio Galisteo, Rio Puerco, and Rio Salado, which are the principal silt-bearing tributaries of the Rio Grande. Only the large area of outcrop on the Chama River is not subject to excessive erosion. Here, because of the high altitude, the climate is more humid and vegetation more luxuriant. Here also many surfaces are covered by a veneer of quartzite and porphyry pebbles of Quaternary age, which, with the help of relatively late lava flows, form an effective barrier to excessive erosion.

First Uplift of the Mountain Ranges

Throughout the long Paleozoic era New Mexico was largely a low-lying country, for much of the time partly covered by the sea. During the Triassic and Jurassic periods the region was mostly dry land but was relatively low. The great thicknesses of Cretaceous and early Tertiary rocks were laid down in seas or on low-lying and at times swampy plains. Strong deformation did not occur in this area until after the Wasatch formation, of Eocene age, had been deposited, when, as shown by Renick,[10] the Sierra Nacimiento was upthrust.

The uplift that initiated the present topography of the region and determined its character as a mountainous plateau was foreshadowed by volcanic activity in late Cretaceous time and by similar activity associated with localized uplift at the end of early Tertiary time. However, volcanic activity and uplift on a large scale began in mid-Tertiary (Miocene) time. Differential uplift and erosion of the mountains and sedimentation in the basins began with this great outburst of volcanism and has continued intermittently to the present day.

Tertiary Period of Volcanism

The Tertiary rocks are now localized in their outcrops by reason of later deformation and erosion. The known centers from which the floods of lava came are relatively few in number, but it seems likely that the lavas from different centers coalesced and that almost certainly the water-laid débris derived from the main areas of accumulation mingled in basins of deposition between the volcanic centers. The mere absence of volcanic rocks cannot be considered evidence that they were not at one time present.

The volcanic centers important in a knowledge of the Rio Grande depression are the San Juan Mountains of Colorado, the Sierra de los Valles, the Datil-Mogollon area, the Organ Mountain area, and the Cerrillos Hills area.

The San Juan Mountain region, in southwestern Colorado, is about 100 miles in diameter. Here, as described by Cross and Larsen,[11] the aggregate thickness of the several groups of lavas and tuffs is more than 33,000 feet, but usually not much more than 5,000 feet is present at any one place. The flows consist of rhyolite, latite, and andesite. Basalt was extruded largely toward the end of the epoch of volcanism, in the flows of Pliocene and later date. These later flows, known as the Hinsdale formation, approximately correspond in time and in type to the flows in the Santa Fe formation and are discussed with that formation.

The Sierra de los Valles area, in the eastern part of the Jemez Mountains, is similar in many respects to the San Juan region except for size. It includes a great thickness of older volcanic rocks, which have been much faulted and deformed. These rocks, largely andesite and rhyolite, are of pre-Pliocene age and appear to have been erupted more or less contemporaneously with the bulk of the San Juan lavas. Volcanism was interrupted by faulting and erosion, and the mountain was much reduced in size, so that the sedimentary deposits of Pliocene time overlapped the region. However, eruptions of rhyolitic as well as basaltic type continued, and a thick tuff member of the Santa Fe formation was formed during the Pliocene. Many of the thin tuff beds of the Santa Fe formation doubtless had their origin in this volcanic center. Volcanic rocks occur in the area between these two centers in detached masses. These are the San Luis Hills, areas in foothills of the Sangre de Cristo Range from Trinchera Creek south to Hondo Creek, hills rising in the basalt plateau such as Cerro Chiflo and Cerro No Agua; and other detached areas. These rocks have been little studied, and whether they represent extensions of the San Juan flows or were extruded from separate vents of about the same age is uncertain.

The Datil-Mogollon area is very large. Great masses of lava and tuff 2,000 to 4,000 feet thick form the mountains and plateaus from the border of the Rio Grande depression, 20 miles west of Socorro, westward into Arizona, and from the Datil Range southward to Silver City. This great region, 60 miles from north to south and more than 150 miles from east to west, has been little studied.

The igneous rock of the Cerrillos Hills and the similar bodies in the Ortiz,[12] San Pedro, and South Mountains

[10] [illegible]

[11] [illegible]

[12] [illegible]

are intrusive rocks of stocklike and laccolithic form, although dikes and sills of the same types also occur. These rocks were intruded into Upper Cretaceous rocks and hence are given an Eocene date. North of the State highway in the La Bajada escarpment, in the gulches leading to Santa Fe Creek northwest of La Bonanza, and elsewhere occur andesite (?) flow breccias, mud flows, and tuffaceous water-laid conglomerates with interbedded rhyolite and basalt flows.

Initial Basins

The end of the great volcanic period merged into the beginning of the series of movements by which the Rio Grande depression was formed, and with the existing meager evidence it is impossible to give the complete sequence of events. It appears, however, that initial basins were formed, into which streams carried gravel and sand derived from the erosion of the previously extruded lavas and into which tuffs from the still-lingering volcanoes were blown or washed by the streams, and that these deposits were deeply eroded and in places faulted before the succeeding Santa Fe formation was deposited. The evidence for these conclusions is somewhat fragmentary, and it is impossible to form a clear picture of the size, shape, or position of these initial basins.

The Santa Fe Formation and the Pliocene Rio Grande

The outstanding characteristic of the Rio Grande is that it flows through broad but not wholly smooth plains between mountains. These plains are underlain by great thicknesses of largely unconsolidated sand and gravel, which are here referred to as the basin deposits. In many localities the existence of these deposits is known very imperfectly from deep wells, but in other places gulches as much as 1,000 feet deep, that have been cut by the Rio Grande and by its tributaries, expose these beds and afford opportunities for study.

For a distance of 40 miles north of the city of Santa Fe the tributaries of the Rio Grande have cut deep gulches in which the deformed beds of the basin deposits are admirably exposed. To this material Hayden [13] in 1869 applied the name Santa Fe marl, and from it Cope [14] obtained vertebrate fossils representing a large fauna which he considered of middle Miocene age. Since that time the beds have become generally known as the Santa Fe formation, and there has been much discussion of the age of the vertebrate fauna. The extensive collections and elaborate studies of Frick [15] indicate that the fauna is of lower Pliocene age. Unfortunately, it is not known whether the fauna occurs at the base or at the top of the formation nor whether the full thickness occurs in the Santa Fe region. In considering other basins whose deposits seem otherwise comparable with deposits of the type locality, correlation is hampered by the scarcity of fossils and by the diverse physical characters of the beds. The existing fossil evidence for the region is not presented in this paper.

The meager finds of fossils indicate that basin deposits of Pliocene age are widely distributed. The further reference of the basin deposits to a single period of deposition contemporaneous with the beds of the type locality near Santa Fe rests on four general criteria: (1) All the beds are slightly cemented, and the finer-grained members have concretions of calcium carbonate; (2) all the deposits are deformed, mostly by normal faults, although in the centers of the basins the deformation is so slight as to pass unnoticed except under intensive search; (3) the beds within any one basin are of diverse lithologic types, ranging from coarse fanglomerate to fine silt and clay, and abrupt changes in the kind and sizes of the contained pebbles are characteristic; and (4) these markedly different materials attributed to one formation conform in their arrangement to a geographic pattern consistent with the laws of deposition in basins. The main body of sedimentary deposits of the Rio Grande depression, from the north end of the San Luis Valley to and beyond El Paso, is considered to be of the same general age and to belong to the Santa Fe formation.

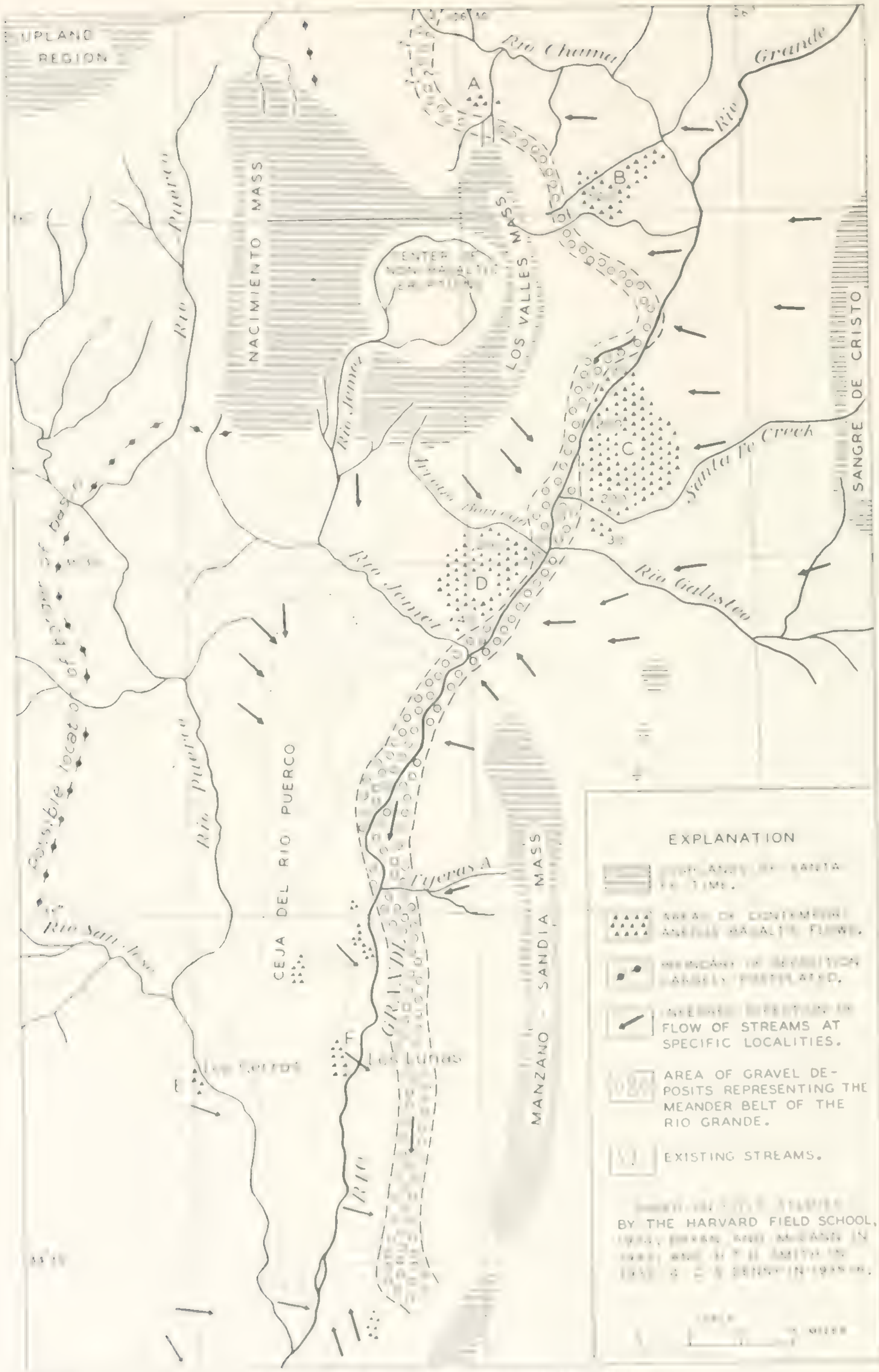
The basins of Santa Fe time were presumably depressed relative to the contiguous highlands by faulting, which seems to have been the dominant geologic process in the area. In places the basins once extended far beyond the present limits of the formation, and the bordering highlands may have been much reduced. Whatever the method of deformation, it is probable that, during the period of filling, the basins were enlarged by erosion of the highlands, and deposition occurred in these border areas. In general, the basins appear to have been elongated into ovals and to be divisible into two major types—basins with a through-flowing river and basins with enclosed drainage.

A basin with a through-flowing river has deposits of a threefold division—the two sets of fan deposits and the axial zone of the river deposits. Each set of fan deposits grades in size toward the axis of the basin but may otherwise be quite dissimilar to the other set in its several parts. The river-laid beds, consisting of

[13] Hayden, F. V., [illegible] of Colorado and New Mexico, 155 pp., 1869.

[14] Cope, E. D., [illegible] of New Mexico, etc.: U. S. Geol. and Geog. Suveys W. 100th Mer. Ann. Rept. pp. 115–130, 1874; [illegible] Philadelphia Acad. Sci. Proc for 1874, pp. 147–152, 1874; On the antelope deer of the [illegible] Santa Fe marls): Am. Naturalist, vol. 9, p. 56, 1875; On the distribution of the Loup Fork formation in New Mexico: Am. Philos. Soc. Proc., vol. 21, pp. 309–324, 1884.

[15] Frick, Childs, New remains of trilophodont-tetrabelodont mastodons: Am. Mus. Nat. History Bull. vol. 59, pp. 505–652, 36 figs., 2 pls., 1933. Matthew, W. D., Fauna lists of the Tertiary Mammalia of the West: U. S. Geol. Survey Bull. 361, pp. 115, 118, 1909.


UPLAND
REGION
Rio Chama
Rio Grande
A
B
C
D
E
F
NACIMIENTO MASS
LOS VALLES MASS
SANGRE DE CRISTO
Rio Puerco
Rio Jemez
Santa Fe Creek
Rio Galisteo
CEJA DEL RIO PUERCO
Tijeras A.
MANZANO - SANDIA MASS
Rio San Jose
Los Cerros
Los Lunas
RIO GRANDE
EXPLANATION
FLOW OF STREAMS AT
SPECIFIC LOCALITIES.
AREA OF GRAVEL DE-
POSITS REPRESENTING THE
MEANDER BELT OF THE
RIO GRANDE.
EXISTING STREAMS.
BY THE HARVARD FIELD SCHOOL,

channel gravel and of sand, silt, and clay deposited on the flood plain, comprise these elements in proportions that are determined by the rate of deposition and the rate of depression of the basin. In general, as these rates increase flood-plain deposits will exceed channel gravel in quantity; as the rates decrease channel gravel may be the only type of material deposited. Wind-blown sand is also likely to occur in association with the flood-plain deposits or may be concentrated in a zone at the lower border of the set of fan deposits on the side of the basin away from the prevailing wind direction.

An enclosed basin has a central or axial lake or playa, the existence of which depends in part on the size of the drainage area, the altitude of the adjacent highlands, and the climate. Such a basin has fan deposits and axial lake or playa deposits. The deposits of salt lakes and playas are similar in character, and criteria for distinguishing them from each other are not completely worked out. A change from salt lake to playa and back again may occur in any basin by reason of fluctuations in climate. In playas silty and sandy clays are deposited in which the evaporating water leaves impregnations and films of gypsum and more soluble salts. These salts may remain as impregnations or may be gathered into scattered crystals or may be more or less completely rearranged in plates in the bedding planes or cracks of the clays. However, large lakes may deposit true clay and fresh-water limestone, or marl, in their central parts, and they are likely to be marked by shore features. On evaporation, they deposit bedded gypsum and beds of the more soluble salts, such as sodium sulphate and sodium carbonate. With good exposures a decision can usually be made as to whether lakes or playas existed in a locality.

The Santa Fe formation was deposited in both drained and undrained basins. Its outstanding characteristic is that, in several more or less separate structural basins the gravel of a through-flowing stream lies near the axis of the basins. These gravel deposits are so thoroughly water-worn and well-shaped and are so cleanly washed as to indicate that they are the deposits of a perennial river that was larger than the present Rio Grande. This river ran from north to south, from basin to basin, much like the present river. On its course the several basins were strung like beads on a cord (fig. 46).

The most northerly known outcrops of the river gravel in the Santa Fe formation are at the north end of White Rock Canyon. Here they are interbedded with pinkish fan deposits that are of coarser grain at each outcrop toward the east and merge into the arkosic fan deposits of the type area of the Santa Fe formation. Flows of andesite-basalt, which become more numerous to the south, are also interbedded. The pebbles of the river gravel range from an inch to more than 6 inches in major diameter and are composed largely of quartzite and massive volcanic rocks. The obvious source for quartzite is in the pre-Cambrian that crops out over large areas to the north. The source for the volcanic pebbles is obviously the San Juan volcanic area, also to the north.

Similar gravel occurs 20 miles farther south, at the south end of White Rock Canyon. Here the river gravel is interbedded with the andesite-basalt flows and also with the tuff member of the Santa Fe formation. From White Rock Canyon the gravels can be followed throughout the Santo Domingo Valley into the Albuquerque and Belen Valleys, where the most southerly outcrops [16] are on the east side of the valley in the gulch leading down from Abo Canyon and also near Contreras. In the more southerly outcrops the largest pebbles are about 3 inches in major diameter and there is, therefore, a slight southerly decrease in size.

The work of Smith [17] shows that not only at the head of White Rock Canyon but elsewhere to the north and west in the Abiquiu quadrangle, the fan deposits of the Santa Fe formation become finer from the base of the Sangre de Cristo Range to the west and south. They also contain much wind-blown sand, as if the border of a river flat were being approached. Basalt flows are interbedded. In Santa Clara Canyon and also near Cerro Pedernal the finer-grained sediments and the basalt flows are cut off and let down to the east and north by the faults that bound the present basin. It is obvious that the formation once continued farther west and south in what is now the elevated Sierra de los Valles mountain region. On the assumption that the river ran on the far side of the contemporaneous lava flows, it should have had a course like that shown in figure 46. That on this course the Pliocene river occupied the position of what is now Chicoma Peak, altitude 11,507 feet, and Cerro Pedernal, altitude 9,867 feet, is a testimony to the amount of post-Santa Fe uplift and erosion. The course of the Pliocene River farther north is uncertain.

To the south of the Belen Basin and specifically of Abo Canyon the course of this ancient river is almost wholly conjectural. Observations by the writer and later work by C. S. Denny make it evident that the Pliocene Rio Grande could not have flowed through the Socorro area. It must have flowed to the east of this enclosed basin and may have had its course over the present Sierra de los Pinos into the Jornada del Muerto, which was in Pliocene time, as at present, a depressed area.

The course of the river still farther south is unknown. Much of the material attributed to the Santa Fe forma-

[illegible]

[illegible] probably belongs to a group of fan deposits. Fine-grained material, such as might have been deposited on a river flood plain, occurs near Las Cruces, beneath La Mesa, and also near El Paso.

Volcanic Rocks Interbedded with Sedimentary Strata of the Santa Fe Formation

Volcanism continued during Santa Fe time but was generally less intense and somewhat different in type from that of the preceding great period of Tertiary volcanism. Outpourings of basalt and andesite-basalt were common, but in the Sierra de los Valles and perhaps in other localities eruptions of rhyolite occurred.

Andesite-basalt was poured out in large quantities in the San Juan Mountains. Cross and Larsen[18] have mapped these lavas as part of their Hinsdale formation. There were numerous local vents, at some of which great thicknesses of basalt were piled up as at Los Mogotes, on the Conejos River, a volcanic pile nearly 1,000 feet high. Generally these basalts are 200 to 500 feet thick. Near the western border of the San Luis Valley the basalt overlies gravel and sand (the Los Pinos member of the Hinsdale formation) and dips gently under the floor of the valley, where it has been found in wells. Near La Jara the andesite-basalt lies 250 to 300 feet below the floor of the valley. At Antonito and for many miles to the south the andesite-basalt is at the surface and forms the western edge of the great lava plateau. South and east of the San Luis Hills the interbedded basalts crop out in San Pedro Mesa and its northerly extension, where they have thicknesses of 50 to 200 feet. The lavas are much deformed by faulting and warping. In the Fort Garland area they are overlain by great thicknesses of deformed fan deposits. On the west side of San Pedro Mesa they are carried down below the surface and have been found in wells in the plains between the mesa and the canyon of the Rio Grande. According to the unpublished work of Upson, the Hinsdale basalt and associated beds are younger than the true Santa Fe.

Lavas interbedded with the sediments of the Santa Fe formation occur in the Abiquiu reentrant. In Santa Clara Canyon Smith[19] has measured 166 feet of basalt in a section of Santa Fe beds 612 feet thick. Other basalt flows occur stratigraphically both higher and lower. Between Santa Clara and Bear Creeks there are 500 feet of interbedded basalt flows. Interbedded flows also occur in Cerro Pedernal and nearby.

The Cerros del Rio is probably the area of most intense eruption in Santa Fe time. Here more than 1,200 feet of lava and cinders, mostly andesite-basalt, were piled up. This great thickness is exposed about midway in White Rock Canyon, opposite the mouth of Rito de los Frijoles. To the north the basalt is interbedded with fan deposits and river gravel. The most northerly tongues of lava extend past Buckman. To the south the basalt is also interbedded in the Santa Fe formation. At the lower end of White Rock Canyon there are only four flows, with a total thickness of about 200 feet. Farther south, on the lower course of Santa Fe Creek, about 200 feet of basalt, including a small cinder cone, forms the walls of a small canyon, and gravel and sand are exposed above and below it. The dip is about 5° east, and one flow forms a cuesta ridge for several miles south.

The next area of interbedded flows is in Santa Ana Mesa, which lies west of San Felipe. This complex plateau consists of the stripped surfaces of the interbedded and deformed basalt of Santa Fe age and two flows that are younger than the Santa Fe. The most easterly outcrops occur in a ridge, east of San Felipe, where two basalt flows, interbedded with fan deposits and river gravel, dip about 10° east. To the west of the river the flows extend westward for 10 miles. The thickness of basalt exceeds 200 feet in places. The so-called Bernalillo Volcano lies just south of this area. According to Renick,[20] this irregular butte consists of a maze of dikes intruded into about 300 feet of fine conglomerate, grit and sand containing a considerable amount of basalt fragments, many of which are scoriaceous and glassy. The sediments are much deformed by the intrusion of the dikes.

Acuma Hill, immediately west of Isleta, is formed of nearly horizontal basalt flows. To the east and north there is only one flow exposed. It dips gently eastward and overlies deformed beds consisting largely of water-laid basaltic cinders. To the north the deformed beds contain less basaltic débris, but beyond a short interval they are again overlain by a basalt sheet which forms the mesa 3 miles north of Isleta. To the east, toward Isleta, there are outcrops of basaltic cinders and cindery basalt. At least 50 feet is exposed, but if, as seems likely, the dip is to the south, the total thickness concealed under the drifted sand of this locality may be much greater. The pueblo of Isleta is built on an outcrop of basalt, which, with the associated terrace gravel, forms a flat-topped hill about 20 feet above the flood plain of the river. Obviously this hill once had a river flat on the west side and hence was the "island" from which the name Isleta is derived. The basalt of the "island" is a much weathered gray rock. It is similar to the basalts in Acuma Hill and seems unquestionably to be the remnant of a flow interbedded in the Santa Fe formation. About 3 miles west of

[illegible]

[illegible]

Acuma Hill there is a low dome of basalt that rises above the level of the Llano de Albuquerque. It also is probably formed of lava of Sante Fe age, as it differs in topographic aspect from the Quaternary flows that lie south of it.

West of Los Lunas, 6 miles south of Isleta, basalt interbedded in the Santa Fe formation forms a high flat-topped butte. On the northwest flank fan deposits containing beds of basaltic debris and a conglomerate of rhyolite-pumice pebbles dip gently to the north and are overlain by about 50 feet of basalt. On the southwest flank fan deposits with two interbedded basalt sheets dip about 10° northwest. In the east flank of the butte there is about 200 feet of basalt in several flows. This block appears to be in fault contact with the western part of the butte.

Los Cerros are a group of ragged hills in the valley of Rio Puerco extending from 1 to 3 miles south of the railroad crossing near the mouth of the stream. Several flows of basalt are interbedded in fan deposits. Faulting has tilted the beds at angles of 10° to 20°, and there are many landslides. The probable thickness and source of this interbedded basalt are not known.

At San Acacia a sheet of andesite forms the gap through which the river runs. Its gentle eastward dip is in accord with the local dip of the Santa Fe formation, and there seems to be little question that it is contemporaneous with the local fan deposits of Santa Fe age.

In the Socorro quadrangle, north of Nogal Canyon, at the base of the mountains, an andesite flow and a basalt flow are interbedded with playa deposits of Santa Fe age. South of the Socorro quadrangle volcanics interbedded in the Santa Fe formation have not been reported.

In the type locality of the Santa Fe formation, 10 miles north of the city, near Pojaoque, beds of volcanic ash, 1 to 5 feet thick, occur in the reddish fan deposits. The materials are well sorted and probably fell from the air and were only in part reworked by streams. On the west side of Santo Domingo Valley water-laid rhyolite ash, containing large fragments of rhyolite and obsidian and one small rhyolite flow, attains a thickness of more than 1,000 feet. It overlies and is interbedded with fan deposits and is faulted with them. The contained fragments and boulders are larger in outcrops near the Sierra de los Valles and the source of the material is obviously in that direction. Near the mouth of Cochiti Creek and north of it this body of tuff thins and is interbedded with and deformed with river gravel and basalt flows of Santa Fe age. It records a period of volcanism in the Sierra de los Valles during Pliocene time. In the Albuquerque-Belen Basin tuff beds, conglomerates of pumice pebbles, and fragments of pumice in fine sands and silts are fairly common. This content of volcanic material can be attributed in part to material contributed to streams by the volcanic activity in the Sierra de los Valles. Part of the material, however, may have been derived from the erosion of still older tuff beds. Volcanic material that perhaps has the same origin occurs in Socorro Valley.

Deformation of the Santa Fe Formation

Because of the cover of later sand and gravel, the Santa Fe formation is concealed in so many places that the amount and character of its deformation may easily pass unnoticed. Many of the early workers in the region failed to observe or else disregarded the deformation. However, in those localities where the beds have been intensively studied deformation is evident and has become one of the principal criteria for distinguishing the formation from the Quaternary sand and gravel. In the centers of the larger basins the dips are low and range from 1° to 5°, or the beds may be so nearly flat as to appear to be undeformed. Adjacent to the borders of the basins the dips usually steepen and range from about 15° to 60°.

Most of the existing mountains and highland areas were also mountainous in Santa Fe time. They were reduced in Pliocene time and were rejuvenated to form the present ranges. Other mountains appear to have been new-born, as, for example, the Socorro-Lemitar uplift. So far as present information goes, all the ranges, with the exception of the Magdalena Mountains and the part of the Sangre de Cristo Range north of Sierra Blanca, owe their present position to the post-Santa Fe uplift.

The pattern of the faults by which the basins underlain by beds of the Santa Fe formation were carried down and the highland blocks uplifted is not completely known. So far as these faults have been discovered or are inferred on reasonable grounds, they are shown on figures 47 to 49.[20a] In areas that have been properly studied and where adequate exposures exist the faults are numerous. Some of the fault patterns are relatively simple en échelon systems; others are complex combinations of groups of faults having trends in three or more directions. The inferred faults are, for lack of detailed information, shown on the maps in simple pattern. There are also within the basin deposits many faults that have not been found or cannot be followed from the single outcrop in which they are expressed, because of the lack of distinctive horizons in the beds.

In general there are two structural types—the more or less symmetric basin and the asymmetric basin. Thus the Albuquerque-Belen Basin appears to have a fault system on both east and west sides. The Santo Domingo and Española Basins are also of this type, although the faulting on the west side of the Española Valley, in the Abiquiu reentrant, appears to have been

[20a] Fault patterns [illegible] revision in detail.


SAN LUIS VALLEY
COLORADO
GEOLOGIC
and
PHYSIOGRAPHIC MAP
Plateau Basalt.
Santa Fe formation.
(Including Hinsdale formation)
Santa Fe Faults.

less severe than that directly opposite, to the east, at the base of the Sangre de Cristo Mountains.

Other structural basins are markedly asymmetric and have a fault system on one side and a depositional contact on the other. The structural basins east and west of the Socorro-Lemitar Range are the best examples. The San Luis Valley northwest of the San Luis Hills is also of this asymmetric type, with depositional contacts on the west side and strong depression to the east and southeast on faults now wholly concealed but easily inferred. In this valley the asymmetry of the post-Santa Fe faulting was preserved by the later Quaternary faulting.

The foregoing discussion raises the question as to rotation of the mountain or highland blocks. How many are true tilted fault blocks? To what extent has the Rio Grande depression been merely let down into the adjacent highland area, which has itself suffered little disturbance in the process? The plateau region west of the Albuquerque-Belen Basin has a folded structure of gentle arches and monoclines broken by faults related in pattern to these folds.[21] These structural features appear not to have been disturbed or deformed by the post-Santa Fe faulting, nor is there any direct evidence of tilting toward the west. Along this border the Santa Fe depression appears to have been carried downward with respect to the plateau as a simple graben. Somewhat similar but less clearly expressed relations exist on the west side of the Abiquiu reentrant.

The Sandia-Manzano-Los Pinos uplift has long been considered a typical fault block.[22] Each of these ranges is capped, more or less completely, by limestone of the Magdalena group, which dips eastward away from the basin. The limestone is resistant to erosion and gives, particularly to the Sandia Mountains, a decidedly asymmetric and youthful aspect. However, as the limestone was deformed both by folding and by faulting in pre-Santa Fe time, the dip of the rocks may be more largely the result of this earlier deformation than of tilting of a post-Santa Fe block. So far as the Manzano Mountains are concerned, the fault boundary with the Santa Fe must lie about 5 miles west of the foot of the range. Red sandstone and shale of presumed Permian age crop out at Hubbel Spring and at Los Ojuelos, localities in the plains west of the mountain front. The Permian beds can be traced eastward from Los Ojuelos to the foot of the mountains, where they lie in fault contact with pre-Cambrian rocks. Thus the range has a front eroded in part from soft Mesozoic rocks, and its border with the Santa Fe is inconspicuous.

The general linear character of the depression is broken by reentrants and offsets. The San Luis Basin (see fig. 47) has a trend east of south as far south as Saguache Creek, where the western border retreats to the west. South of Saguache Creek the basin has a north-south trend. The eastern border also changes to a north-south trend at Mosca Pass, beyond which this irregular-shaped basin is cut off by a northwestward-trending fault on the northern flank of the San Luis Hills.

The area southeast of the San Luis Hills, conventionally a part of the San Luis Valley, is marked by a strong reentrant about 10 miles deep and 40 miles long, the Fort Garland-Costilla reentrant. As shown by Upson [23] this area is outlined to the east by a complicated set of faults and more or less shut off from the basin by the outcrop of basalt in the Santa Fe formation in San Pedro Mesa and its northern extensions.

The great plateau that extends southward from the San Luis Valley is presumably a representative of the basins. However, the western boundary is so masked by basalt that the structural relations are not clear and have not been adequately studied. A large number of hills of older rock project from the lava plain and doubtless represent portions of the bordering highlands. The hills of pre-Cambrian rock, such as Cerro Aire and Cerro Montosa, and hills of Tertiary volcanic rock, such as Cerro No Agua and Cerro Chiflo, must represent an almost complete closure of the depression.

The eastern border of the depression has a great reentrant from Hondo Creek south beyond Taos, a distance of 15 miles. Thus in the vicinity of Taos the mountain front is set back 10 miles to the east. The plains are mostly undissected and, as there are almost no outcrops of the basin deposits, the assumption that this reentrant originated by faulting is largely inferential. (See fig. 48.)

In the next section to the south the eastern border extends westward in the great Picuris prong of crystalline rock as far as the present canyon of the river. Against this prong the basin deposits are down-faulted in what appears to be a simple pattern to the north and a more complex one to the south. Directly south of this prong is the Picuris reentrant, more or less outlined on the north by faults. However, on the eastern border and part of the southern border the Santa Fe has a depositional contact on the older rocks, but its disturbed condition within the reentrant gives assurance that this also is a structural depression.

Almost directly opposite the Picuris prong and reentrant is the Abiquiu reentrant, about 20 miles from

[21] Hunt, C. B., and Dane, C. H., Preliminary map [illegible] the San Juan Basin, U. S. Geol. Survey, [illegible]

[22] An [illegible] that of Darton, [illegible] other ranges as being faulted anticlines (Darton, N. H., "Red Beds" and associated formations in New Mexico, [illegible] Bull. 794, p. 99, 1928.)

[23] Upson, J. E., unpublished data.


NORTH-CENTRAL
NEW MEXICO
GEOLOGIC
and
PHYSIOGRAPHIC MAP
BY
present stream grade.
Andesitic and Rhyolitic lavas.
Basalt mesas at high levels.
Basalt interbedded in the Santa Fe formation.
Santa Fe formation, usually covered.
Post-Santa faults.
Highland areas.
CONJOS MOUNTAINS
Taos
Cerro Pedernal
Embudo
Cochiti
La Bajada
San Felipe
Cerrillos
ORTIZ MT
SAN PEDRO MT
SOUTH MT

north to south and 20 miles from east to west. The fault systems of this area are obscured by overlying lavas, but Smith [24] has found a complicated pattern to the north and south. On the south the faults appear to belong to an en échelon system. Each fault has a more or less north-south or northwest-southeast trend, but the whole system provides for letting the Santa Fe down on a more or less east-west line. On the northern border of the reentrant the fault pattern is more complex.

Separating the subbasin west of Santa Fe from the Santo Domingo Valley is a prong of older rocks projecting northwest from the Ortiz Mountains. The Cerrillos Hills, composed of andesite intrusions and other crystalline rocks, form the southern portion of this prong. The northern portion is blanketed by Quaternary basalt, so that there is no distinction on the surface between this prong and the basalts of Santa Fe age that form the Cerros del Rio. The west side is marked by a strong north-south fault which passes through Rosario siding. The east side is covered by Quaternary gravel, but doubtless detailed study will show the presence of faults.

The Santo Domingo Valley lies in the area in which the 20-mile offset between the general axes of the basins to the north and those to the south is accomplished. Apparently both the north and south boundaries of the structural depression are marked by series of north-south faults arranged in more or less en echelon systems. Folds and faults, largely unmapped, affect the basalt interbedded in the Santa Fe that forms White Rock Canyon to the north of the valley. Later flows of rhyolite conceal most of the structure west of the river in this vicinity. There are deformed lava beds of Santa Fe age in part overlain by Quaternary basalt, in the south-central part of the area in Santa Ana Mesa. In the western part of the area near the northern border, east of Jemez, the Santa Fe formation is much faulted and older rocks are exposed in places. Part of this complicated structure has been mapped by Reiche [25] and is shown on figure 49.

The Albuquerque-Belen Basin thus offset with respect to the northern Espanola-Santa Fe Basin has a general north-south trend. It is one of the largest and most symmetrical of the basins. The eastern boundary lies at the base of the Sandia-Manzano-Los Pinos uplift. The plains are so little dissected and are so thoroughly covered with Quaternary alluvium that the faults are almost wholly inferred. However, at the mouth of Tijeras Canyon east of Albuquerque, at a point just east of the Candelaria ranch, the brecciated fault face on the granite is exposed on the south side of the canyon, and on the north side there is a small exposure of deformed gravel.

The northwestern border consists of four en echelon faults, each increasing in throw to the south and offset to the west.[26] There are also several subsidiary parallel faults. To the south of the Cerro Colorado the boundary of the Santa Fe crosses the Rio Puerco in a southwesterly direction. Faults are probably present, but this area is unmapped. From a point near the mouth of the Rio San Jose the fault has been mapped by Darton [27] as far south as Arroyo Pato. Here there is an unmapped interval before reaching the fault at the base of the Sierra Ladron. Denny [28] has shown that in the area east of the Sierra Ladron the Santa Fe is faulted against a pre-Santa Fe formation, which is in turn faulted against the older rocks on the line shown by Darton on the map above cited. The post-Santa Fe fault thus lies somewhat farther east, as shown on figure 49.

The general effect of these two fault systems on the east and on the west is to enclose a basin which has a general north-south trend. It is in the nature of a true graben or dropped block, 25 to 35 miles wide and 80 miles long.

The Socorro Basin is structurally diverse. From San Acacia south for 15 miles it is a narrow asymmetric trough, with its deepest portion near the complicated fault system at the base of the Socorro-Lemitar uplift. On its eastern margin the Santa Fe thins to a wedge and rests unconformably on the older rocks of the low plateaus to the east. (See fig. 50.)

Near San Antonio this narrow trough widens. Great plains underlain by Santa Fe beds extend to the Magdalena and San Mateo Ranges and also between them. To the east the basin merges with the Jornada del Muerto. This great depression is doubtless underlain by the Santa Fe formation, but it is almost wholly covered by later Quaternary and recent deposits.

South of San Marcial faults are known along the west base of the Fra Cristobal Range and Sierra Caballo. Faults are also reported north of Rio Percha, outlining a small graben between the foot of the Black Range and a group of outlying hills to the east. This graben has a north-south trend, but there is no information as to its shape in cross section. It lies parallel to the Jornada del Muerto, which is presumably also a down-faulted basin. Still farther south only two localities are known where the Santa Fe rests in fault contact with the older rocks. As Dunham [29] points out, there is little question that the basins are underlain by more or less deformed beds presumably of Santa Fe age. The surface of the basins, such as that of the Jornada del Muerto, are erosion surfaces cut on these beds. The faults by which the defor-

[24] Smith, H. T. U., op. cit.

[25] Reiche, Parry, unpublished [illegible]

[illegible] 2145 [illegible] 15

[26] Bryan, Kirk, and McCann, F. T., The Ceja del Rio Puerco, a border feature of the Basin and Range province in New Mexico (in press).

[27] Darton, N. H., "Red Beds" and associated formations in New Mexico, with an outline of the geology of the State: U. S. Geol. Survey Bull. 794, pl. 26, 1928.

[28] Denny, C. S., unpublished data.

[29] Dunham, K. C., op. cit., pp. 174-183.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Jemez

mation was accomplished are concealed. Dunham assumes that a fault exists on the east side of the Organ Mountains, and Sayre,[30] of the United States Geological Survey, has demonstrated a fault at the east base of the Franklin Mountains by geophysical means.

Development of Existing Topography

Ortiz Surface

The Rio Grande depression is a structural depression consisting of minor basins and reentrants and having a border of diverse types that merges to the south into a number of similar basins. The structural depression is only in part coincident with the present course of the river.

Broad surfaces of erosion slope toward the present position of the river course in several localities. These surfaces are capped by gravel characteristic of the existing tributaries and in places are protected by basalt flows. They represent one or more long periods of erosion with stabilized grades. By projecting the gradients of the individual surfaces toward the Rio Grande it appears that they would reach the position of the river about 500 feet above its present channel throughout the Albuquerque-Belen Basin.

This surface, as thus projected from existing remnants, represents a long period of erosion that followed the post-Santa Fe uplift of the mountains. From the particularly well-displayed and long-studied remnants around the Ortiz Mountains, it is called the Ortiz surface. During this period the Rio Grande was about 500 feet above its present position at White Rock Canyon, and about 450 feet above its present position at the mouth of the Rio Puerco. By the end of the period a considerable part of the material of the basins was carried away; the basins, except some areas of interbedded lavas, were wholly reduced to plains; parts of the bordering highlands were beveled; and the original fault scarps were largely destroyed. The larger highland masses retained most of their original altitude except for the stripping of the wedges of the Santa Fe formation that overlapped their borders. On the flanks of the larger masses and within the smaller masses only the resistant rocks, such as quartzite, limestone, granite, and the Tertiary volcanics, stood out as residuals. The Mesozoic and early Tertiary sedimentary rocks were much reduced. For example, the area of the upper Rio Puerco is a part of the bordering highland of the Albuquerque-Belen Basin. Here practically all the Mesozoic rocks except the Poleo sandstone were reduced in Ortiz time.[31] On the Ortiz surface the Rio Grande attained what is essentially its present course, and with each successive lowering of gradient, it has merely preserved this course or modified it by minor adjustments to the position of hard and soft rocks.

In the area north of White Rock Canyon the Ortiz surface is not easily distinguished from other and higher surfaces. South of the Albuquerque-Belen Basin, this surface has not been certainly identified. It may be coincident with the top of the Jornada del Muerto and La Mesa. These surfaces lie about 450 feet above the river near San Marcial and 350 to 370 feet above the river near El Paso. On the west side of the Jornada del Muerto large areas of Cretaceous rocks are beveled at grades corresponding to this level. The present course of the Rio Grande west of the Jornada del Muerto was undoubtedly established at this time.

Post-Ortiz Deformation and Deposition

In general the Ortiz surface appears not to have been much deformed. However, Smith [32] believes that some deformation has occurred in the Chama Valley and that there has been progressive uplift in Quaternary time. It may be that, as the correlation of the pediments and terraces is perfected, warping in different localities may be established. Some areas, particularly north of White Rock Canyon, may have been broadly uplifted.

Uplift of the ranges in Quaternary time has been established in the San Luis Valley and at the west base of the Magdalena Mountains.

The portion of the San Luis Valley north of the San Luis Hills has been depressed in post-Santa Fe time and may be subject to continuing movement. As Siebenthal [33] pointed out, a large number of artesian wells penetrate fine sand and clay, which continue from the surface downward for several hundred feet. To this material, which is obviously post-Santa Fe, he applied the name Alamosa formation. Near La Jara wells penetrate to basalt that is considered to be of Hinsdale age and therefore younger than the Santa Fe formation. Here the depth of the Alamosa formation is between 350 and 400 feet. Elsewhere in the valley the depth is probably greater, but no sharp division from the underlying beds can be made in the existing well logs.

The Alamosa formation is exposed in Hanson's Bluff, where 41 feet of sand, fine gravel, and clay is overlain by 8 feet of more recent gravel and conglomerate. The beds contain large numbers of shells representing animals that live in fresh water, belonging to four species that are usually attributed to the late Pliocene or early Pleistocene.

Except for this exposure, the characteristics of the Alamosa formation must be inferred from the well logs. Those published by Siebenthal indicate that the material is fine-grained, but it seems probable that there is more gravel than is indicated by these logs. Siebenthal

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30 Sayre, A. N., informal communication.

31 Bryan, Kirk, and McCann, F. T., Successive pediments and terraces near Cuba, N. Mex.: Jour. Geology, vol. 44, pp. 145–172, 1936.

32 Smith, H. T. U., op. cit.

33 Siebenthal, C. E., op. cit., pp. 40–41.


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TEXAS

believed that the beds were laid down in a lake, but against such a theory there can be cited several facts. No gravel embankments or other shore features are known. A deep lake would provide no mechanism except the feeble activity of wave-induced currents for the transportation of sand from west to east, yet sand is shown in every well log and occurs in Hansons Bluff. Furthermore, alkaline and colored waters are found in the wells of the present area of alkali and swamp—that is, to the north of the Rio Grande fan. It is believed that water of this type indicates ground-water discharge throughout the period of deposition of the Alamosa formation rather than the existence of a lake. It thus seems probable that the valley floor was gradually lowered with deposition, and that the beds were laid down on alluvial plains similar to those of the present time. Temporary lakes may have existed as incidents to subsidence or as a result of the shifting of areas of rapid deposition from place to place. The existence of the Alamosa formation testifies to deformation and the bold western scarp of the Sangre de Cristo Mountains is also evidence of relatively late fault movement on the east side of the basin.

The northeast base of the Magdalena Mountains is marked by a line of fault scarps about 5 to 40 feet high, extending almost continuously from the north end of the range southeastward to Water Canyon. These scarps are somewhat weathered and brush-covered but record a recent uplift of the range relative to the plains. The Snake Ranch Flats, which lie between the Magdalena and Socorro Mountains, are drained by streams heading on the Magdalena Range which join La Jenze Creek or pursue courses across the Socorro uplift. The flats are smooth, aggraded slopes to which each storm adds new material. Wells in the flats penetrate alluvium that cannot be differentiated in the logs from the underlying Tertiary sediments. It is evident, however, that this is a basin originating in Pleistocene or recent time and still in the process of being filled.

Post-Ortiz Erosion Surfaces

By the time the Ortiz surface was completed the river appears to have been established in essentially its present course, but nevertheless the later history of the Rio Grande is complex. The river in New Mexico lowered its channel but remained stabilized at successive stages for considerable periods of time.

With each successive lowering of the river channel, the tributary streams were also incised, and broad plains of erosion were cut.[34] In the Santo Domingo Valley, where detailed studies [35] have been made, there are two well-developed surfaces, or partial pediments, below the Ortiz the La Bajada and Peña Blanca pediments. Between the Peña Blanca pediment and the present flood plain there are two terraces.

The La Bajada surface is well displayed near the village of La Bajada. In some places it is nearly complete, but in others it is only a partial pediment. It continues south into the Albuquerque-Belen Valley, where it forms most of the surface of the Llano de Sandia. If projected to the river it corresponds to a river level about 300 feet above present channel. In the Socorro region it appears to be the same as the Tio Bartolo [36] surface. Exact correlation from the Rio Grande up the Rio Puerco has not been accomplished, but apparently the La Bajada is the equivalent of the La Jara pediment near Cuba.[37]

The Peña Blanca surface is less developed than the La Bajada and represents a stabilization of the grade of the river for a shorter period. It corresponds to a river channel about 175 feet higher than that of the present. It is prominent just east of Bernalillo and forms much of the complex bench west of the river called the Segundo Alto. In the Socorro area it apparently corresponds to the Valle de la Parida surface,[38] and on the Rio Puerco to the Rito Leche.[39]

Still farther down the river, in the Mesilla Valley, Dunham [40] has distinguished the Picacho surface, which reaches the river about 100 feet above its present channel. Dangerfield [41] has distinguished two less developed surfaces which reach the river at lower altitudes and also a terrace 20 feet above the river.

The Present Flood Plain and Associated Terraces

Since the pediments were formed the present flood plain has developed, and two types of low terraces have been formed. The first type results from the deposition of fans by tributaries and subsequent lateral planation by the river. The river changes its course from one side of its flood plain to the other at frequent intervals, and many such changes have occurred since the Spanish conquest. Whenever the river flows at one side of its flood plain, the tributaries that enter from the opposite side build fans on the flood plain. The larger tributaries build large fans very rapidly and may raise their channels 20 to 50 feet at their emergence upon the flood plain. In many places the fans of tributaries coalesce to form foot slopes, or "ladera", at the base of the bluffs that bound the flood plain. When the river shifts its course, however, it cuts laterally at the base

[34] Bryan, Kirk, and McCann, F. T., Successive pediments and terraces of the upper Rio Puerco in New Mexico: Jour. Geology, vol. 44, pp. 145-172, 1936.

[35] Bryan, Kirk, and Upson, J. E., unpublished data.

[36] Bryan, Kirk, Pediments developed in basins with through drainage as illustrated by the Socorro area, N. Mex. (abstract): Geol. Soc. America Bull., vol. 43, pp. 128-129, 1932.

[37] Bryan, Kirk, and McCann, F. T., op. cit., p. 160.

[38] Bryan, Kirk, op. cit.

[39] Bryan, Kirk, and McCann, F. T., op. cit., p. 164.

[40] Dunham, K. G., Geology of the Organ Mountains, etc.; New Mexico School of Mines, Bur. Mines and Min. Res., Bull. 11, p. 179, 1935.

[41] Dangerfield, A. N., unpublished data.

of the fans and may wholly remove them, and the tributaries also readjust their grades and dissect their previously deposited fans. By swings of the river from side to side, there are formed low terraces of irregular height. This process was described many years ago by Keyes,[42] who attributed to it all the terraces of the Rio Grande and even the higher erosion surfaces, or pediments. The process occurs to some extent on all rivers, and it is of particular importance in the valleys of the great rivers of arid regions. The terraces of this type are formed at irregularly spaced intervals of time, dependent on the vagaries of the shifting river. Their height depends on the size of the tributaries and the length of time during which the fan was built before a shift in the river course put a stop to deposition.

The second type of terrace differs from the type just described in that it is built by the main river, not by the tributary. It is composed of the characteristic rounded gravel and clean sand of the river, not of the relatively unsorted and angular gravel and sand of the intermittent and ephemeral tributary streams. Such terraces represent a cutting downward and an upbuilding of the river grade. The Rio Grande, however, is relatively so powerful in lateral planation on its present grade that it has largely removed the deposits that it laid down at the higher grades formerly existent.

The broad flood plain of the river is one of its conspicuous features. Except in the constrictions between the successive valleys, the flood plain is from 1 to 4 miles wide. Here are the irrigated lands, the oases, whose products in food and in hay concentrate the population. Here are the markets and the centers of civilization for the widely scattered ranches and mining camps of bordering highlands.

The deposits underlying the flood plain consist of unconsolidated sand, gravel, silt, and clay. Some of these sediments have been deposited recently, and in fact there seems to be no question that the river channel and the flood plain have been rising in the last few years. The depth of the flood-plain deposits constitutes an unsolved problem. The river in its larger floods scours deeply and rehandles the previously deposited materials. In such periods of high water it is capable of handling gravel that at ordinary times is unknown in the river bed. The depth to gravel in the river bed is thus a rough measure of the depth of scour in great floods. In installing its diversion weirs the Middle Rio Grande Conservancy District found gravel at depths of about 30 feet below the low-water channel at the Angostura dam, between San Felipe and Cochiti, at the Isleta dam, and at San Acacia. Near Albuquerque the piers of the Barelas Bridge are set in a bed of gravel at a depth of [illegible] feet. Thus it appears that scour in the larger valleys is deeper than in the constrictions between them. Scour during flood only gives a minimum depth of the flood-plain deposits. Thus wells near Albuquerque find loose material to a depth of 200 feet, more or less, and the mineral character of the water is more or less uniform to this depth. These facts indicate that the flood-plain deposits, resting on the Santa Fe formation, have a maximum thickness of at least 200 feet. At El Paso drilling at the so-called international dam site at the head of the gorge showed, as reported by Slichter,[43] a depth of 86 feet of sediments above bedrock. It seems probable that there is in the larger valleys from 100 to 250 feet of relatively recent deposits of flood-plain type above the Santa Fe formation.

Post-Ortiz Volcanism

Contemporaneous with the development of the Ortiz surface there was extrusion of basaltic lava. Part of this lava may have been poured out before the surface was wholly complete and may account in part for the preservation of surfaces slightly above the normal Ortiz grade. Basalts attributed to Ortiz time in this sense include the "plateau basalts" of the Rio Grande Canyon, the Vallecitos and Black Mesa basalts of the Abiquiu area; the basalt of the Alto de Mesa Santa Ana, the great flows of Mount Taylor and the Mesa Prieta, the high-level basalts south of the Rio San Jose, those in the southern part of the Socorro Mountains, and the San Marcial flow.

During the stages following the Ortiz, basaltic lava flows were poured out in different localities. In the Abiquiu area a small basalt flow was extruded on the Santa Clara (La Bajada?) surface. The largest flows were extruded near the beginning of the La Bajada stage from craters north of White Rock Canyon. These lavas poured into the canyon of the river and, joined by other basalt from now concealed vents, completely blocked it. The river level was raised above the La Bajada level of 300 feet and changed in position. The new canyon was similarly blocked and lava sheets welled over the partly dissected Ortiz surface at altitudes more than 500 feet above the river. The basalt from north of the canyon flowed on the east side of the Cerros del Rio and joined lavas from cinder cones north and south of Santa Fe Creek to form an extensive basalt sheet whose remaining portion is the Mesa Negra de la Bajada, extending eastward from the escarpment at La Bajada. The river cut a new canyon but was again displaced by floods of rhyolitic mud descending from a great cone that formed in the Sierra de los Valles at this time. This mud consolidated into great sloping sheets that reach more than

[42] [illegible]

[43] [illegible]

1,000 feet in thickness. The river was permanently displaced to the east, and the location of the present White Rock Canyon was fixed at this time.

The formation of the thick deposits of rhyolitic mud does not represent the last important eruption of the Sierra de los Valles. Apparently long afterward, when the cone that had formed at this time was much eroded, new volcanoes, including the present Cerro Redondo, were formed. Obsidian flows from these eruptions were carried only a short distance down Jemez Creek. Thereafter, the only activity came from the south flank of Cerro Redondo, where a small pumice cone broke out at the locality called El Cajete. Pumice from this eruption was blown out with great force, and small bodies of it can be found east and south of the Jemez many miles distant from the source. The date of this eruption is at least as late as Peña Blanca time, as bodies of this pumice have been found on surfaces of this stage near Cochiti.

Near the pueblo of San Felipe a small cone is the center of a late basalt flow that mantles the Santa Fe lavas of Santa Ana Mesa and extends down upon the Peña Blanca surface. An erosion outlier east of the river is the round butte that is called Mesa San Felipe.

The Albuquerque volcanoes consist of five small cones and a small field of basalt. The basalt lies mostly on the Llano de Albuquerque, which is a remnant of the Ortiz surface. At the north end the lava flowed down upon the Segundo Alto to levels about 150 feet above the river, and therefore the eruption probably occurred within the Peña Blanca stage.

West of Los Lunas, on the Llano de Albuquerque, there is a considerable area of late basalt. It is associated with a mass of lava of Santa Fe age which forms a broad dome to the north. It may, however, be distinguished by its greater freshness of aspect, by the sharpness of its cinder cones, and by its extension down a broad swale cut a little below the ancient surface of this plain. It seems probable that this flow is much later in date than the broad Ortiz surface on which most of it lies.

In various localities to the south there are basaltic lava flows which generally lie on erosion surfaces and are apparently of about the age of La Bajada and Peña Blanca surfaces. There are flows at the south end of the Socorro Mountains, at the south end of the Sierra los Pinos near Hillsboro,[44] and near the Elephant Butte Dam, in the Sierra Caballo. On the west slope of the Mesilla Valley[45] there is a small cone and lava flow on the Picacho surface, of equivalent date. There are also large areas of basalt on La Mesa which were doubtless extruded more or less in the Picacho stage and thus long after the erosion surface of La Mesa was formed.

[44] Harley, G. T., op. cit., pp. 31–33.

[45] Dunham, K. G., op. cit., p. 178.

Summary of Ground-Water Conditions

General Statement

The topography and geology of the Rio Grande drainage area significantly affects its water supply. The topography affects the water supply directly because it very largely determines the amount and distribution of the precipitation. There is, in general, in the Rio Grande drainage area an increase in precipitation with altitude. Thus there is a general increase in precipitation from south to north with increasing altitude. The inner valleys and the San Luis Valley are in the rain shadow of the mountains and therefore have low precipitation. These facts are well shown by the rainfall map of the Rio Grande drainage area.[46] At altitudes above about 7,000 feet much of the precipitation occurs as snow, which tends to sustain the flow of the streams in the spring and summer. The slope of the surface also influences the amount and rapidity of direct run-off, and conversely the amount of infiltration and of ground-water recharge and ground-water run-off, which sustains the flow of the streams.

The distribution of the rocks of different kinds also affects the amount and rapidity of the direct run-off and the amount and rate of infiltration into the ground. The texture of the rocks and the size, shape, and position of the rock bodies largely determine the amount of ground-water recharge, storage, and discharge. Thus the stratigraphy and rock structure control in large degree not only the distribution, depth, and yield of the wells but also the distribution, yield, and constancy of the springs and therefore of the streams that are fed by definite springs or by diffused seepage. The stratigraphy and rock structure are also the principal factors that determine the chemical character of the water derived from wells, springs, and spring-fed streams.

Mountains and Highlands

The mountains and highlands that border the Rio Grande depression not only receive a greater precipitation but also have a higher proportionate rate of run-off than the intervening basins. They consist largely of consolidated rocks whose pore spaces are small and moderate in number. Generally these rocks are fissured and jointed and may in places be covered by a mantle of soil. There is some storage of water in these weathered portions of the rocks, but even under favorable conditions storage in most of the formations is only moderate in amount, and, because of steep slopes and deep-cut canyons, discharge from these natural underground reservoirs is easy, and at the end of long dry summers it may be almost complete. Under these circumstances springs dry up and streams have little or no water. The largest ground-water recharge occurs in some of the limestones and basalts.

[46] See pl. 3, pt. I.

The San Juan Mountains are not only the largest mountain range bordering the Rio Grande depression but also among the highest, having many summits above 12,000 feet. The precipitation exceeds 50 inches in places, and there is much winter snow. Here rise the Rio Grande and its strong headwater tributaries—the San Antonio, Conejos, and Alamosa Rivers. The greater part of the mountain area is blanketed with volcanic rocks that have an average thickness of 5,000 feet. These rocks have numerous joints and cracks, and most of them weather to fairly deep soils. There are also considerable areas of glacial drift and of landslide masses. All these characteristics of the area provide storage of groundwater that is discharged into the streams at the bottoms of the deep-cut canyons. The low-water flow of the river and its tributaries is largely maintained from these sources.

The Sangre de Cristo and Culebra Ranges in Colorado are high, reaching altitudes of 14,000 feet. The mountains are steep and the drainage basins narrow. The rocks are mostly pre-Cambrian granite and schist, which have been scraped clean by glaciation and are therefore little weathered. There is thus a quick run-off and little ground-water storage, and most of the streams have only a small low-water flow. The larger streams, Culebra and Costilla Creeks, have headwater canyons on the east side of the crest and thus reach into areas of sedimentary rock from which they draw a relatively large low-water flow because there is relatively more soil and greater ground-water storage. In New Mexico this range is wider, and in the interior there are belts of Pennsylvanian limestone, shale, and sandstone. Thus in spite of lower altitudes and less precipitation, many of the creeks, such as the Rio Colorado and Santa Fe Creek, have relatively sustained low-water flows.

The Chama River heads in the southern part of the San Juan Mountains, in the Conejos Mountains in New Mexico. The annual precipitation reaches 40 inches on the higher summits of this range. There is moderate ground-water storage in the weathered rock and in masses of glacial débris. The Chama River not only has a large spring flow from melting snow but also a considerable low-water flow.

The Jemez Mountains are about 40 miles square but consist of two unlike portions. The west side is the Sierra Nacimiento consisting mostly of granite and schist flanked on the west by upturned sedimentary rocks. The north end of the range, San Pedro Mountain, has a summit area of more than 100 square miles above 10,000 feet. Here the relatively deep winter snows and ground-water storage provide a water supply for creeks draining into the Chama River to the north, the Rio Puerco to the west, and the Rio de las Vacas, a tributary of Rio Jemez. All have a small low-water flow in summer. The eastern part of the range, the Sierra de los Valles, is made up largely of volcanic rocks. The most extensive formation is a rhyolite tuff which is open and porous. It forms great plateaus with a small direct run-off and large ground-water storage. Springs that break out at the base of the tuff furnish the low flow of streams such as the Rio Jemez. The formation also contributes to the ground-water discharge of the Rio Grande in White Rock Canyon.

The Sandia, Manzano, and Los Pinos Ranges reach altitudes exceeding 10,000 feet, but the mountains are narrow and the drainage basins of the streams have very small areas at the higher altitudes. Most of the streams drain to the Rio Grande through gaps in the range. Most of the limestone plates that cap the mountains dip eastward. They are much broken by joints and have large solution cavities. The direct run-off is moderate and there is large ground-water storage, but the dip of the rocks is so steep that drainage of these reservoirs by springs is relatively easy. The distances to the river from these springs, some of which are large, is so great that no perennial streams from them reach the Rio Grande.

The western upland bordering the Albuquerque-Belen Basin is largely underlain by Cretaceous and Tertiary sedimentary rocks. Here originate the Rio Puerco and the Rio Salado, two important tributaries of the Rio Grande. The Rio Galisteo, which rises in the south end of the Sangre de Cristo Range, east of the Rio Grande, has the larger part of its drainage basin in the Cretaceous rocks and has similar characteristics. Quick run-off and low ground-water storage are characteristics of these rocks. The general altitude of the drainage basins is also low, and most of the precipitation is rain rather than snow. Sharp flashy floods are characteristic. The rocks weather largely to sand, silt, and clay. The clay resulting from the weathering of these rocks is colloidal, and when it is wet it can be easily transported by the streams. During a long period of time alluvium was stored in the flood plains of the main streams and their tributaries, but beginning about 1885 deep channels were formed from downstream headward, and even yet these channels are continuing to widen and, in places, to deepen. The erosion of these channels has produced large volumes of fine-grained material, commonly called silt,[47] which is carried into the Rio Grande and which since the building of the Elephant Butte Dam has been deposited in the Elephant Butte Reservoir. If the estimated volume of the original channels of the Rio Puerco is subtracted from the volume of the channels as determined in 1927 and the remainder is divided by 42, the

[47] [illegible]

number of years between 1885 and 1927, the result is the mean rate of silt production by enlargement of the channels. This figure is 9,000 acre-feet a year, or about 10 percent of the quantity of silt annually deposited in the Elephant Butte Reservoir. If the very considerable quantity of silt produced by channel widening and deepening in the Rio Galisteo and the Rio Salado is added, it is apparent that these three tributaries are the major factors in the silt problem of the Rio Grande. It is also evident that channel enlargement is a prime factor in silt production.

The highlands and mountains south of the Albuquerque-Belen Basin are relatively small and relatively low. None of the tributary streams are perennial, and many of them seldom yield even flood water to the river. Part of the Jornada del Muerto and most of La Mesa contribute no surface flow to the river. The largest tributaries originate in the Black Range. The volcanic rocks of this range furnish good ground-water storage, and some of the streams have a low-water flow, which is, however, consumed by evaporation or infiltration into the basin deposits and thus fails to reach the river.

The Basin Deposits

Classification of the basins.—The basins between the mountains are characterized by low rainfall, low direct run-off, and high ground-water storage. In this respect they resemble the other basins of the basin and range province. They differ from those other basins principally in being strung like beads along the line of the Rio Grande. Each has its local drainage area and local water supply and discharges water by evaporation and transpiration in the low land of its inner valley, but each also receives and discharges water of the main river and some of them of major tributaries also.

The intricacies of the individual basins can be best understood if the hydraulic regime of ground-water reservoirs is first considered. Ground-water reservoirs in the Rio Grande depression may be divided into two main classes and these in turn may be subdivided as follows:

A. Geologically enclosed basins, in which the permeable rocks, consisting chiefly of parts of the Santa Fe formation, later sedimentary deposits, and associated lava rocks, are completely surrounded by essentially impermeable bedrock, so that virtually all water that is precipitated on the basin or comes in by surface flow from other drainage areas must either be consumed within the basin or overflow across the bedrock by surface flow. These basins may be divided into the following subtypes:

1. Basins that are enclosed hydrologically as well as geologically. The basin receives no water from any other basin, and all the precipitation within its drainage area is consumed by evaporation, transpiration, or chemical combination, without flow to the outside.

2. Geologically enclosed basins that receive surface flow from other basins but do not discharge any surface water. All precipitation within the drainage area of the basin and the accretion of water by surface flow from one or more other basins is consumed within the drainage area of the basin by evaporation, transpiration, or chemical combination.

3. Geologically enclosed basins that discharge water by surface flow but do not receive any surface flow from any other basin. All precipitation within the drainage area of the basin is consumed by evaporation, transpiration, or chemical combination, except for the loss by surface flow to the outside.

4. Geologically enclosed basins that receive surface flow from one or more other basins and also discharge water by surface flow. All precipitation within the drainage area of the basin plus the surface inflow is consumed by evaporation, transpiration, or chemical combination, except for the loss by surface flow to the outside.

B. Geologically open basins, in which the permeable rocks (Santa Fe formation, later sedimentary deposits, associated lava rocks, etc.) are incompletely enclosed by bedrock or are incased by bedrock part or all of which is permeable. Thus the basin is geologically open, and there is opportunity for water to percolate underground into or away from the basin. The hydrologic connection may be effected through bodies of permeable bedrock. These basins also may be subdivided, as follows:

1. The basin has no surface inflow from any other basin and no surface outflow, but it loses water by percolation to one or more other basins that have lower water tables.

(*a*) The loss is large, so that the basin has a low water table. Precipitation in the drainage area of the basin is consumed by immediate evaporation and transpiration from the soil, by chemical combination, and by underground leakage.

(*b*) The loss is small, so that the basin has a high water table. Precipitation in the drainage area of the basin is consumed by evaporation, transpiration, and chemical combination as in a geologically enclosed basin except for the loss underground.

2. The basin has no surface inflow from any other basin and no surface outflow, but it receives water by percolation from one or more other basins that have higher water tables.

3. The basin receives surface flow from other basins and either loses or gains water by percolation.

(*a*) Underground loss large.

(*b*) Underground loss small.

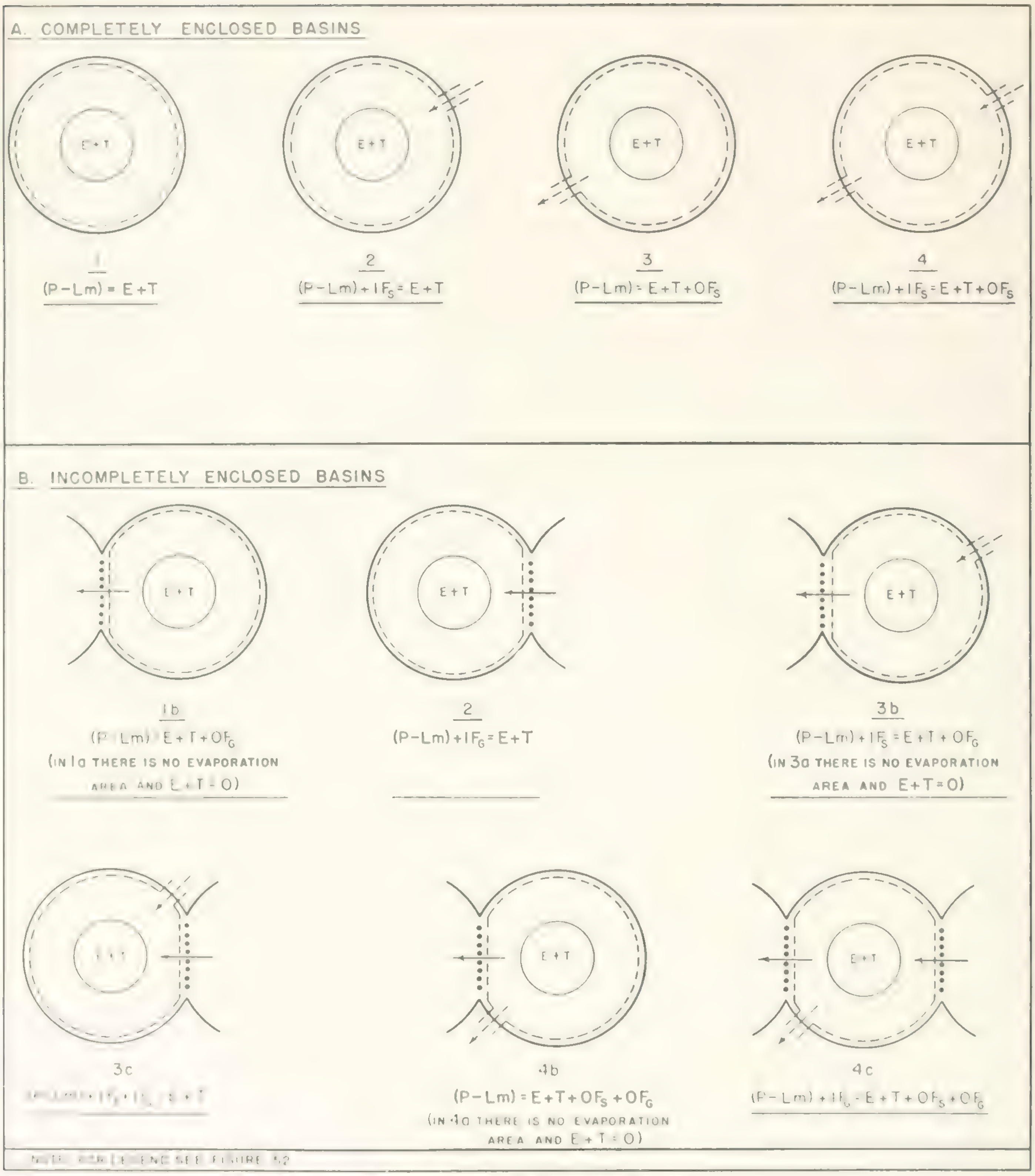
(*c*) Underground gain.

4. The basin has surface outflow and either loses or gains water by percolation.

(*a*) Underground loss large.

(*b*) Underground loss small.

(*c*) Underground gain.


A. COMPLETELY ENCLOSED BASINS
E+T
1
(P-Lm) = E+T
2
(P-Lm)+IF$_S$ = E+T
3
(P-Lm) = E+T+OF$_S$
4
(P-Lm)+IF$_S$ = E+T+OF$_S$
B. INCOMPLETELY ENCLOSED BASINS
1b
(IN 1a THERE IS NO EVAPORATION
2
(P-Lm)+IF$_G$ = E+T
3b
(P-Lm)+IF$_S$ = E+T+OF$_G$
(IN 3a THERE IS NO EVAPORATION
AREA AND E+T=0)
3c
4b
(P-Lm) = E+T+OF$_S$+OF$_G$
4c

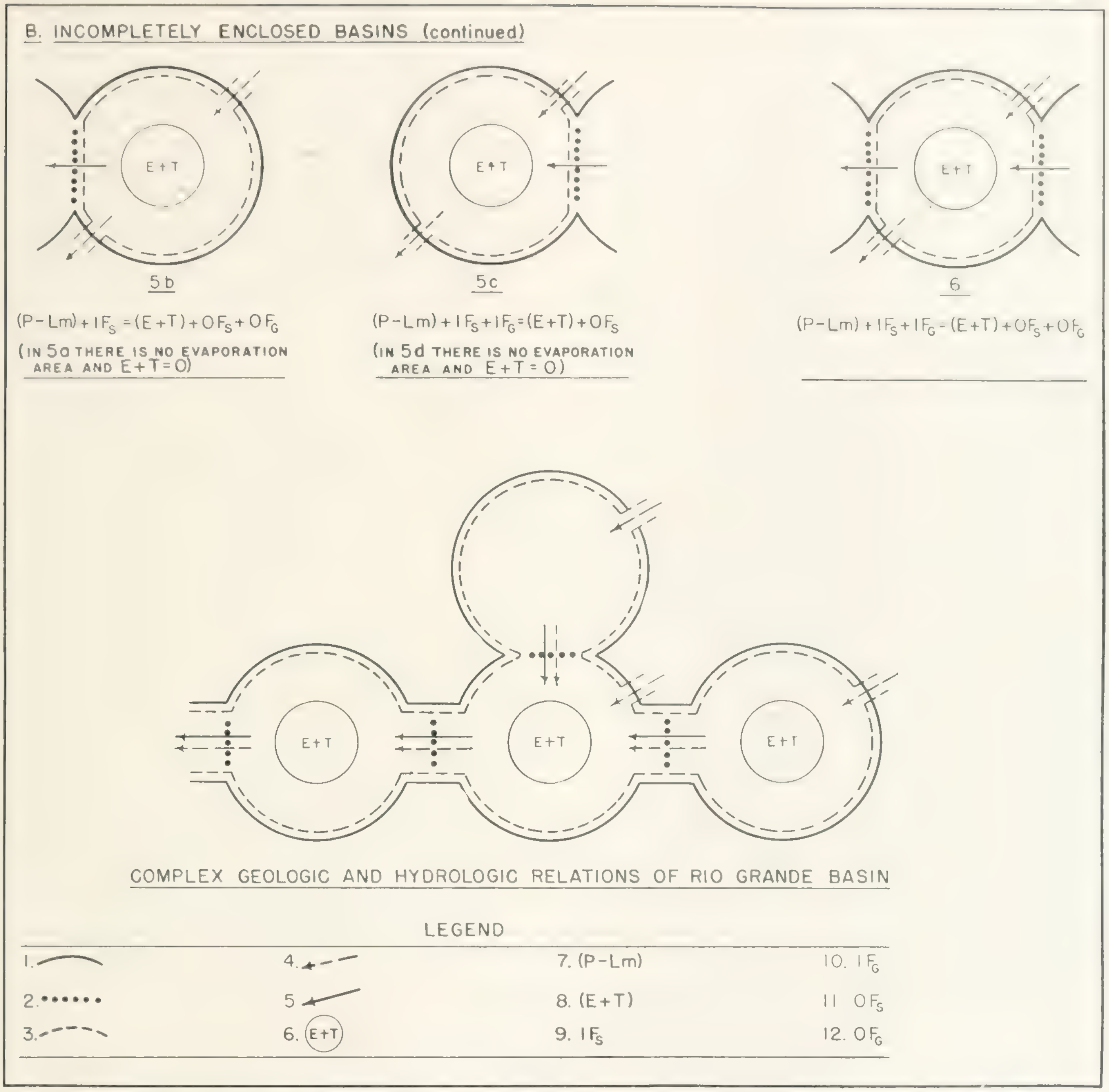


FIGURE 52. Ground-water basins "incompletely" enclosed and diagram showing complex geologic and hydrologic relations of the Rio Grande Basin

EXPLANATORY NOTE

1. Impermeable boundary of ground-water basin.
2. Permeable boundary of ground-water basin.
3. Topographic and drainage boundary.
4. Flow of surface water.
5. Flow of ground water.
6. Conventional representation of area of shallow ground water or shallow lake with intense evaporation and transpiration.
7. Approximate quantity of infiltration; equal to the amount of precipitation on the basin less the immediate loss from the soil by evaporation and transpiration.
8. Quantity of water lost from basin by evaporation and transpiration from the ground-water body.
9. Quantity of water brought into basin by surface streams.
10. Quantity of water brought by underground flow.
11. Quantity of water lost to basin by flow in surface streams.
12. Quantity of water lost to basin by underground flow.

5. The basin has both surface inflow and outflow, and either loses or gains water by percolation.

(a) Underground loss large.

(b) Underground loss small.

(c) Underground gain.

6. The basin has both surface inflow and outflow and also underground inflow and outflow.

The accompanying diagrams, figures 51 and 52, have been prepared without regard to the size and shape of the basins and considering only the possible variations in geologic and hydrologic conditions. The simpler basins, A–1 and A–2, do not occur in the Rio Grande drainage area, but the Estancia Valley and the plains of San Agustin are nearby examples, and many additional examples could be cited from Nevada and southeastern California.

The basins of the Rio Grande drainage area are open geologically and also open hydrologically. As they are surrounded by higher ground, however, they generally gain rather than lose underground water. The only possibility of loss underground is to the next lower basin on the river. However, some of them are so nearly enclosed both geologically and hydrologically, even at their southern or lower ends, that they are, except for the surface flow of the Rio Grande, almost perfectly isolated as to water supply from adjacent basins. As nearly all the basins receive surface or ground water from sources other than the river, however, most of the basins classify in B–5–c or B–6.

Hydrology of the basins.—In the light of the general principles set forth above the several basins of the Rio Grande can be reviewed. The San Luis Valley is almost completely closed geologically by the barrier of the San Luis Hills to the south. South of Antonito there is no known barrier to underground flow through the gravel and basalt into the plateau and thence to the canyon of the river. However, only water that infiltrates in the Hinsdale formation in Los Pinos Creek Valley or near the mouth of Antonito Creek could travel in this direction, as the slope of the surface and of the water table are to the east and north from Antonito northward. Furthermore, seepage studies in Rio Grande Canyon show no notable gain of water in this area.[48] In this same area surface water, in part diverted from other streams, goes down Poncha Creek for use in irrigation south of the San Luis Hills. The basin of this creek is wholly in the relatively impermeable Tertiary volcanics (Conejos? andesite), and there is probably little leakage to the deep underground. Whatever is lost by wastage at the end of the canals goes into the river and is lost to San Luis Valley. In the area between the Sierra Blanca and the northeast end of the San Luis Hills the basin is open to the drainage of Trinchera Creek. As Trinchera Creek is the higher, both surface and ground water may be fed into San Luis Valley, but part of the water, both surface and underground, goes south of the barrier and is lost to the valley.

The eastern portion of what is called San Luis Valley south of Trinchera Creek drains both on the surface and underground to the Rio Grande. Part of the water from the lower part of Culebra Creek enters above State Line Bridge (Lobatos gaging station) a few miles north of the New Mexico line. The ground water in the vicinity drains directly west only in part, and much of it must mingle with the ground water from Costilla Creek in the permeable beds that underlie the plain and must reach the river south of State Line Bridge.

The great plateau south of the San Luis Hills has a low surface run-off and high rate of percolation into the ground. Thus on the west side only a very few streams reach the Rio Grande and these have generally only small and discontinuous flows in the basalt plateau. On the east side of the plateau several streams originating in the Sangre de Cristo Range reach the river. Costilla and Latir Creeks, the Rio Colorado, Hondo Creek, and Taos Creek are the principal streams. Each stream enters the Rio Grande Canyon through a narrow and usually short canyon. These streams carry to the river relatively large quantities of water, and each has a small but substantial low-water flow. However, the Rio Grande also gains water from the ground between the State Line Bridge and Embudo.[49] This invisible inflow as measured on eight occasions between 1911 and 1928 amounted on the average to 119 second-feet. Deducting for evaporation losses leaves a net gain of about 100 second-feet, or 73,000 acre-feet a year.

The mean difference in flow between the Embudo and State line stations for the period 1889 to 1926 is, in round numbers, 250,000 acre-feet a year. Of this quantity, 187,000 acre-feet is accounted for by the surface flow of the Rio Colorado, Hondo Creek, Taos Creek and the Rio Embudo. Thus only about 63,000 acre-feet is to be accounted for by the remaining streams and by the ground-water inflow. It appears, therefore, that the mean ground-water flow must be considerably less than the 73,000 acre-feet a year shown by the special measurements of 1911 to 1928. If the quantity is as much as 50,000 acre-feet, there is in the 75 miles of canyon a ground-water inflow of 650 acre-feet to the mile.

The Española Valley receives both surface and ground water from the Abiquiu reentrant and also from the Picuris reentrant. It receives surface and ground water from the Tesuque Valley near Buckman. There is, however, a surface and ground-water divide between Tesuque and Santa Fe Creeks. This divide lies in the Santa Fe formation, and there is no impermeable

[48] [illegible]

[49] [illegible]

barrier. The surface and ground water of Santa Fe Creek and of an area extending about 20 miles south to the north brink of the Galisteo Valley drains to the canyon of Santa Fe Creek in the Mesa Negra de la Bajada. Here the ground water is brought to the surface by a barrier of older rocks formed by Tertiary, Permian, and Cretaceous rocks and intrusives in the Cretaceous. Some of it is lost by evaporation and some spills through the barrier and emerges again above the village of La Bajada.

The White Rock Canyon is a topographic separation between the Española and Santo Domingo Valleys. It is cut mostly in the interbedded basalts of the Santa Fe formation and at levels 300 feet or more above the river in later volcanics. These rocks are permeable to water. They probably form only a partial obstruction to water flowing southward from the Española Valley. Without question they transmit water from both sides but particularly from the west side of the canyon. Springs are common in the canyon, and there is a gain of water not only from the creeks but also from the ground.

The Santo Domingo Valley is bounded on the east by a geologic barrier composed of different rocks which are apparently effective in preventing movement of ground water. Some ground-water flow breaks out in Santa Fe Creek above La Bajada, derived from such water as overflows the barrier and also water that originates by reason of rainfall on the mesa. The interbedded basalt that crops out in Black Butte is crossed by Santa Fe Creek in a canyon east of Cochiti. Here also ground water is brought to the surface and in part dissipated by evaporation. The Rio Galisteo, which drains a large area of highland outside the basin, crosses into the basin at Rosario siding, and thence to the river flows in a flood plain with a high water table where some ground water is lost by evaporation. Several streams flow in from the mountains on the west. All lose their surface flow at the boundary of the Santa Fe formation and contribute to the ground water.

The Albuquerque and Belen Valleys lie in a very large basin. The topographic barrier between the valleys is at Isleta, and as it is formed by a basalt sheet interbedded in the Santa Fe formation it offers only a partial obstruction to the flow of water underground. Otherwise the Albuquerque and Belen Valleys constitute a unit. Surface waters from outside the basin are received in one or the other of these valleys through Jemez Creek and Rio Puerco and from the east side of the Sandia and Manzano Mountains through Placitas, Tijeras, Hell, and Abo Canyons. At its south end the Belen Basin is much narrowed between the Sierra Ladron and the Joyita Hills. The fault on the west side forms the boundary between the Santa Fe formation and the pre-Santa Fe basin deposits. The latter are generally more thoroughly cemented and are less permeable, but there is some opportunity for ground-water connections. The actual gap at San Acacia is a narrow gorge in a sheet of andesite interbedded with the Santa Fe formation. The flood plain in this gap is narrow, and underflow in it through the flood-plain deposits must be reduced to a minimum.

The Socorro Valley is underlain by beds of the Santa Fe formation deposited in a basin separate from the main basin. The lithology of the beds is somewhat different, but there is no reason for believing that their permeability is lower except in a zone 1 to 2 miles wide at the base of the Socorro and Lemitar Mountains. This basin merges to the south into the Jornada del Muerto and the basins west of the river. Leakage to these basins is impossible on account of their higher altitude, but on the other hand ground-water inflow must take place from these areas. Whether ground water from the inner valley in the vicinity of San Marcial can pass west of the Elephant Butte Reservoir depends largely on hydrologic conditions. When the reservoir is full, the valley fill is saturated with water to an altitude close to that of the town of San Marcial, and there is no hydraulic gradient on which movement can take place. When the reservoir is empty or at low level there is a gradient, but whether it is enough to cause significant movement is doubtful.

Rincon Valley is largely enclosed on the east and north. It is open to the west, but this part of the basin is higher and must contribute water to rather than gain water from the Rio Grande Valley. At the lower end of the basin, in Seldon Canyon, the basin is not wholly closed, but it is so narrow that ground-water losses are almost impossible except through the gravel below the river bed.

Mesilla Valley is almost closed at both ends, but is open to the sides. It seems from the somewhat meager information available that ground-water levels in La Mesa are higher than the floor of the valley and that there must be a ground-water gain. Loss of ground water into Mexico west of El Paso seems unlikely, as the enclosed basins to the south appear, according to a reconnaissance by A. N. Sayre, of the United States Geological Survey, to have altitudes higher than the valley floor above El Paso. The gorge at El Paso has at least 86 feet of alluvium above bedrock, and Slichter's measurements [50] show that underflow is small.

El Paso Valley is open on both sides and ground-water gains occur, but it is so constricted at Fort Quitman that ground-water losses in this pass are probably low.

[50] Slichter, C. S., Ground water of the Rio Grande [illegible]: U. S. Geol. Survey Water-Supply Paper 141, pp. 9-14, 1905.

PART II
SECTION 2.—GROUND WATER IN THE SAN LUIS VALLEY, COLORADO[1]

Introduction

Location and General Features of the Area

The San Luis Valley, in the south-central part of Colorado, lies in a broad depression between two mountain ranges converging to the north. The Sangre de Cristo Range, which forms the east boundary, reaches altitudes of over 14,000 feet. The ranges on the west side include the Saguache, San Juan, Conejos and La Garita Mountains, with altitudes between 13,000 and 14,000 feet. The valley floor has an altitude ranging from about 7,500 to about 8,000 feet. Alamosa, near the center of the valley, lies at an altitude of about 7,540 feet. The San Luis Valley is the first of a series of basins along the Rio Grande, below its head in the San Juan Mountains of Colorado.

The entire length of the valley from north to south is about 150 miles, and its greatest width is about 50 miles. The San Luis Hills, extending northeast from Antonito on the south to Fort Garland on the east, separate the valley into two parts. This report deals only with that part lying north of these hills, which is hydrologically distinct from the south part. The area covered by this report lies chiefly in Alamosa and Saguache Counties but partly also in Conejos, Costilla, and Rio Grande Counties.

The Rio Grande enters the valley at Del Norte, on the western border, and flows southeast across the valley in the direction of Alamosa, there turning abruptly south toward the San Luis Hills, passing through them in a narrow gap. A low divide, located a few miles north of the Rio Grande and parallel to it, separates topographically the area to the north. This area is generally referred to as the closed basin area. The Conejos River, which rises in the western mountains, flows east and then northeast along the western flank of the San Luis Hills to join the Rio Grande. In addition, there are numerous smaller streams.

Most of the valley has a remarkably flat surface, with the lowest portion along an axis near the eastern border of the valley. From this low land the valley floor rises to the foothills, steeply toward the east, and more gently toward the west, at first not more than 3 to 6 feet to the mile but gradually increasing toward the margins of the valley.

Alamosa, the county seat of Alamosa County, is the largest town in the valley. According to the census, it had a population of 5,107 in 1930. The next largest town is Monte Vista, whose population in 1930 was 2,610. Smaller towns in the valley include La Jara, Center, Del Norte, Sanford, Antonito, Manassa, Fort Garland, Saguache, Moffat, Hooper, and Mosca.

The entire valley floor is underlain by a body of unconfined water at shallow depth. The only large use that is at present made of this body of ground water is from a number of standby irrigation wells in the agricultural area on the west side of the valley. These wells are pumped in periods of water shortage. Beneath the body of shallow ground water and separated from it by a confining bed lies a large body of artesian water, which occurs in numerous strata in the basin deposits or the valley fill. The artesian water has been developed extensively for domestic, stock, and irrigation uses, over 6,000 flowing wells having been drilled in the valley.

The geology and ground-water conditions of the San Luis Valley were studied and described by Siebenthal.[2] The geology is reviewed by Bryan in the preceding section of this report.

Acknowledgments

The ground-water work was begun on March 11, 1936, by T. W. Robinson, assisted by H. A. Waite, who began work April 21, 1936. From April 15, 1936, to January 15, 1937, A. DiGiacomo devoted part of his time to establishing and measuring periodically the depth to water in observation wells. He also assisted in the inventory of artesian wells. On July 17, 1936, G. M. Dyer was assigned to the inventory of artesian wells, continuing with this work until January 9, 1937. E. F. Taylor was employed in the period from November 9, 1936, to January 16, 1937, to run levels to observation wells.

Grateful acknowledgment is made to George M. Corlett, attorney for the Rio Grande Water Users' Association, for general information regarding the use of water in the valley; to W. D. Carroll, irrigation division engineer, and Dan Jones, Jr., deputy State

[1] [illegible]

[2] [illegible]

hydrographer for the San Luis Valley, for cooperation and data supplied by them; to I. R. Richardson, president of the Adams State Teachers College at Alamosa, and M. G. Hester, superintendent of buildings, for laboratory facilities and office space. C. R. Bollier, city water commissioner at Alamosa; W. F. Bowers, city manager of Monte Vista; Hugh H. Collum, of Center; and C. H. Hall, of La Jara, furnished valuable information regarding the number and discharge of artesian wells in the respective towns. Special acknowledgments are due to Grant E. Oxley, Robert E. Schwarzbeck, Horning Bros., Axel Arnell, Victor Crow, E. P. Wagner, and Mr. Van Nostrand for cooperation in the use of their wells in field tests. Ray Wells, Charles Speiser, A. E. Biggs, and T. C. Shepherd, well drillers in the valley, gave valuable information regarding artesian wells. W. A. Haynes, of Center, gave freely of his time, spending several days in the field, in supplying information concerning irrigation wells. Acknowledgments are also due A. M. Collins, Howard K. Linger, J. H. Oliver, and Ben King, who control large tracts of land on the east side of the valley, for data furnished in regard to artesian wells, and to the many residents of the valley for their wholehearted cooperation in supplying information at all times.

General Ground-Water Conditions

Practically all the ground water that occurs in the water-bearing beds of the valley fill in the San Luis Valley is meteoric in origin—that is, it is the result of precipitation in the form of rain or snow on the valley floor and on the tributary drainage area. By far the greater part of the precipitation on the drainage area falls as snow. A part of the precipitation that falls directly on the valley floor percolates downward to fill the interstices of the sedimentary deposits, while a part of the run-off of the streams discharging into the valley percolates away from the stream channels as contribution to the ground water. Recharge to the ground water from the latter source is materially aided by the numerous gravity diversions for irrigation. The common method of irrigation is by "subbing" or subirrigation. In this method large quantities of water are spread over the land surface in order that they may percolate downward to saturate the underlying material and raise the ground-water level. Sufficient water is spread over the land to raise the ground-water level to the root zone of the plants and to maintain it in that position throughout the growing season. Saturation of the aquifer, however, is not by simple downward percolation but is the resultant of downward percolation in the areas of recharge and lateral percolation away from those areas.

The upper surface of a zone of saturation, except where that surface is an impermeable body, is known as the water table.[3] Such a zone of saturation corresponds to the water in a reservoir and is often referred to as a "ground-water reservoir". Its upper surface—the water table—is free to rise during periods of recharge or to fall during periods of discharge, similar to the water surface in an ordinary reservoir. The quantity of water represented by a rise or fall of the water table, however, is far less than that represented by a rise or fall of the same magnitude in a reservoir of equal size. The quantity of water stored in a ground-water reservoir depends on the capacity of the rocks of the aquifer for water, as ground water occupies only the interstices or voids in the rock. As in an ordinary reservoir, however, the rise and fall of the water table is an index to the quantity of water which has been added or withdrawn. When the capacity of the rocks to absorb water is known, the quantity of water represented by a rise or fall of the water table can be determined.

Over most of the floor of the San Luis Valley there occurs such a zone of saturation. The water that occurs in the zone of saturation in the shallow valley fill is known as unconfined or shallow water. Locally it is often referred to as the "sub."

When the upper surface of a zone of saturation is composed of an impermeable body the water is said to be confined. If the water is under sufficient pressure to rise above the zone of saturation it is called artesian water.[4] If the hydrostatic pressure is sufficient, the water may rise in a well to the land surface and may flow from the well. As the hydrostatic pressure in the water-bearing bed fluctuates, the water in the well will rise and fall accordingly. Unlike fluctuations of the water table, these fluctuations are not necessarily an index to additions or withdrawals of ground water. The water moving through such a confined water-bearing bed may be compared to water moving through a conduit, the water-bearing bed being really a large natural conduit filled with permeable material through which the water moves under pressure. If the cross-sectional area of the water-bearing bed, the hydraulic gradient of the water, and the coefficient of permeability of the material are known, the quantity of water passing through the bed can be determined for any period of time.

Such a body of ground water occurs in the valley fill at greater depths than the unconfined water in the shallow valley fill. This body of confined or artesian water also constitutes a ground-water reservoir.

These two bodies of ground water will be discussed in order of their occurrence beneath the land surface.

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[3] Meinzer, O. E., Outline of ground-water hydrology, with definitions: U. S. Geol. Survey Water-Supply Paper 494, p. 32, 1923.

[4] Idem., p. 40.

Unconfined (or Shallow) Ground Water

Extent and Hydrologic Character of the Aquifer

Areal extent and thickness.—Valley fill is present over most of the San Luis Valley from Poncha Pass on the north to and beyond the New Mexico State line on the south. It is broken only by the San Luis Hills, which trend northeast from Antonito to Fort Garland and form an almost complete barrier across the southern end of the valley. The area to the south of the San Luis Hills is economically and socially a part of the San Luis Valley, although geologically and in part hydrologically it is distinct. The ground-water studies were confined to the part of the valley north of the San Luis Hills.

In this part of the valley, the shallow valley fill is limited on the west by the foothills of the Conejos, La Garita, and Saguache Mountains, on the north by the converging Saguache Mountains and the Sangre de Cristo Range, on the east by the Sangre de Cristo Range, and, as already pointed out, on the south by the San Luis Hills. In the central part of the valley the deposits above the confining beds are composed mainly of clays and sands with some gravel. Along the edge of the valley floor, bordering the foothills, the material is composed of coarse sand and gravel. Narrow tongues of alluvium and torrential wash extend up the valleys of the larger streams, especially those of the Rio Grande and Conejos Rivers.

The thickness of the shallow valley fill, considered as the depth to the first confining bed, ranges widely over the valley floor. At Moffat, in the trough of the valley, clay occurs at a depth of about 10 feet. In the vicinity of Swede Corner, 13 miles west of Moffat, it occurs at depths of 10 to 15 feet, and in the Nash well, about 5 miles east of Moffat, Siebenthal [5] reports yellow clay at a depth of 85 feet. On the Rio Grande alluvial fan 9 miles southwest of Center, the irrigation well of E. P. Long, in sec. 4, T. 39 N., R. 7 E., penetrated gravel and sand to a depth of 90 feet without encountering any clay beds. At the G. E. Oxley irrigation well, in sec. 13, T. 39 N., R. 8 E., about 9 miles east of south from Center, clay was reported at a depth of 50 feet. In the vicinity of Hooper, the first clay bed of consequence is reported from 80 to 90 feet. The depth to clay is reported as about 60 feet at Monte Vista, and about 50 feet at Parma, 6 miles southeast of Monte Vista. In the vicinity of Alamosa, clay beds have been encountered at depths ranging from 15 to 40 feet. In a well near the Bowen School, in sec. 31, T. 37 N., R. 8 E., a bed of blue clay was struck at a depth of 30 feet. About 2 miles southwest of the Bowen School, Siebenthal [6] reports hard clay at 60 feet. At the State fish hatchery, half a mile south of La Jara, clay was encountered at a depth of 30 feet. In the town of Sanford clay was found at 32 feet, and at Romeo at a depth of 17 feet. A test well in Antonito, near the apex of the Conejos alluvial fan, encountered lava rock at a depth of 50 feet. The foregoing figures give some idea as to the thickness of the shallow valley fill in various parts of the valley.

Relation to the artesian aquifer.—Beneath most of the valley plain the ground water in the shallow valley fill (shallow water) is separated from the ground water in the deep valley fill (artesian water) by beds of impermeable or only slightly permeable clay. Along the edge of the valley floor and opposite the canyon mouths, however, this clay parting feathers out, for wells drilled far up on the alluvial fans and along the edge of the valley floor do not pass through clay beds. Deep wells drilled farther from the edge of the valley and in the interior of the valley pass through one or more clay beds. The log of the well drilled by the Denver & Rio Grande Western Railroad at Villa Grove, on the alluvial fan of San Luis Creek, indicates that the well penetrated 960 feet of gravel and sand with no clay.[7] On the Rio Grande alluvial fan, a pumped irrigation well (No. 12J4G1) owned by E. P. Long penetrated 90 feet of sand and gravel. A dry hole in the southwest corner of sec. 6, T. 36 N., R. 8 E., on the alluvial fan of Gato Creek, is reported to penetrate coarse gravel and sand to a depth of 163 feet.

Siebenthal [8] reports several wells along the eastern margin of the valley in which no clay beds were encountered, as follows:

> On the Baca grant a mile and a quarter northeast of the village (Crestone) in the fork of North and South Crestone Creek, a bore went 410 feet in boulders. On Dead Man Creek a bore 1,100 feet deep was all in sand. At the Willie Hansen ranch 2 miles northwest of Baldy station, on the Denver & Rio Grande Railroad, a number of wells have been bored just about at the margin of the flowing-well area. One in the NE¼ sec. 17, T. 37 N., R. 12 E., is 500 feet deep, reported all in sand. Near the middle of the north side of sec. 10, T. 37 N., R. 12 E., a well is reported 300 feet all in sand. Near the middle of the west side [illegible] gravel.

Although well logs are not available along the entire margin of the valley, it seems probable that there is a strip of the valley adjacent to the foothills that is underlain by little, if any, clay. In regard to this strip, Siebenthal [9] says:

> Though it is evident that the clay beds of the water-bearing series are replaced at about this point by sand and gravel, it is not likely that they terminate so abruptly. It is probable that small clay beds have been overlooked in the wells near the edge of the flowing-well area.

[5] [illegible]
[6] [illegible]

[7] [illegible]
[8] [illegible]
[9] [illegible]

The ground water in this marginal strip is unconfined and is the source for both the shallow and artesian water of the valley. From this common source, the ground water moves laterally toward the valley, part of it passing beneath the clay beds to become artesian water and part moving out into the permeable materials on top of the clay beds.

General character of the materials.—The material which forms the shallow valley fill ranges from silt to coarse gravel. The finest material is found in the trough of the valley, particularly in the closed basin area, whereas the coarsest material is found in the alluvial fans and outwash slopes along the edge of the valley. Large alluvial fans have been built by the streams entering the valley from the west side, the largest being that built up by the Rio Grande. Pronounced fans have also been built by Gato, Alamosa, and La Jara Creeks and by the Conejos River. Along the east side of the valley the alluvial fans are not large, but are so numerous that they coalesce along their lateral margins to form a steep, gravelly alluvial slope, skirting the foot of the mountains. The alluvial fans on the west side of the valley are much flatter and more extensive than those on the east side.

The difference in the shape and size of the alluvial fans on the east and west sides is due to the difference in the character of the streams entering the valley. The streams entering from the west head far back in the mountains and receive the drainage from innumerable tributary streams and canyons that drain extensive areas of high altitude and heavy precipitation. These streams are much gentler in gradient than those entering the valley from the east, but they discharge floods of much greater volume and duration and consequently are capable of carrying large loads of detrital material. The detritus is not heaped about the mouths of the canyons but is spread widely, some of it being carried several miles into the valley.

Streams entering from the east side are steeper and shorter and do not receive much drainage from tributaries. Although they head high in the mountains they do not drain extensive areas, and the precipitation is not as heavy as in the drainage areas of the western tributaries. Consequently the floods are flashy, and most of the detritus is deposited near the mouths of the canyons to form steep alluvial fans.

The coarsest material, consisting almost entirely of poorly assorted gravel, is found at the apices of the alluvial fans. In general the material in the west-side fans is coarser than that in the east-side fans. In the upper part of the west-side fans it is not uncommon to find gravel as large as 8 and 10 inches in diameter, whereas in the east-side fans gravel of this size is not so common. Toward the lower end of the fans the gravel becomes progressively finer. In the central trough of the valley only small amounts of gravel are in evidence, by far the larger part of the valley fill being composed of sand, clay, and silt.

Some idea as to the character and distribution of the material that makes up the shallow valley fill is furnished by the following two tables of well logs, consisting entirely of wells that were bored to determine the depth to the shallow water.

TABLE 1.—*Logs of observation wells in the closed basin area*

[illegible]

Well number and log	Thickness (feet)	Depth (feet)	Well number and log	Thickness (feet)	Depth (feet)
5M32N1—(X-25):			7K1R1—(E-8):		
Clay and adobe	[illegible]	4.9	Fine sand and clay loam	2.3	2.3
Sand and clay	.4	5.3	Fine sand [illegible]	1.7	4.0
Sand and gravel	1.4	6.7	Sand and gravel	2.7	6.7
6K14D1:			7K3N1—(E-11):		
Adobe	2.0	2.0	[illegible]	3.0	3.0
Sandy soil	1.5	3.5	Clay, sand, and gravel	2.0	5.0
Fine soil	.5	4.0	7K4N1—(E-[illegible]):		
6K17D1:			Clay loam	1.6	1.6
Black [illegible]	2.0	2.0	Large gravel and sand	2.5	4.1
Sandy soil	1.0	3.0	7K6N1—(E-14):		
Gravel	1.0	4.0	Sand, [illegible], and gravel	8.2	8.2
6L1D1:			Clay, gravel, stones	3.9	12.1
Adobe soil with pebbles	6.3	6.3	7K7A1—(E-[illegible]):		
Fine sand	.2	6.5	Clay	2.8	2.8
6L4B1:			Sand	1.4	4.2
Sandy clay soil	17.0	17.0	Clay	1.3	5.5
Sand	1.0	18.0	Sand and clay	2.3	7.8
Clay	[illegible]	[illegible]	7K10A1—(E-10):		
6L4R1:			Clay	2.6	2.6
Adobe soil	3.5	3.5	Sand and gravel	3.6	6.2
Fine sand	.5	4.0	7K16R1:		
6L19B1:			Sandy soil	2.0	2.0
Adobe soil	3.0	3.0	Fine sand	2.5	4.5
Soil and fine sand	2.1	5.1	7K25A1:		
Gravel, medium to course	1.6	6.7	Adobe	2.5	2.5
6L28N1:			Fine sand	2.0	4.5
Adobe brown soil	2.0	2.0	Coarse sand	2.0	6.5
Sandy soil	1.4	3.4	7K30D1:		
Gravel, medium to coarse	2.2	5.6	Sandy soil	[illegible]	[illegible]
6M5B1:			7K33R1:		
Adobe soil	5.0	5.0	Clay	1.0	1.0
Fine sand	.5	5.5	Sandy clay	5.0	6.0
6M6R1—(X-24):			Fine sand	1.7	7.7
Clay	4.0	4.0	7L1R1—(E-2):		
Clay, some sand and gravel	.9	4.9	Clay loam	1.1	1.1
Sand and gravel	1.4	6.3	Heavy clay	1.9	3.0
6M7R1—(X-2[illegible]):			Clayey sand	1.4	4.4
Clay	4.0	4.0	Sand and pea gravel	2.1	6.5
Sand and clay	1.3	5.3	7L2R1—(E-3):		
Sand and pea gravel	1.3	6.6	Fine sand and clay	1.3	[illegible]
Sand	.7	7.3	Sand	4.5	5.8
6M9A1—(X-22):			Clay	.5	[illegible]
Clay	4.4	4.4	Fine sand	3.0	9.3
Sand and clay	.6	5.0	7L3R1—(E-4):		
Sand	2.7	7.7	Clay	1.2	1.2
6M19R1—(X-21):			Sand [illegible]	3.0	4.2
Clay	4.6	4.6	Coarse sand	2.2	6.4
Sand and clay	.4	5.0	Blue sand and pea gravel	[illegible]	10.0
Fine yellow sand	1.7	6.7	7L4R1—(E-[illegible]):		
Sand	.6	7.3	Clay	1.8	[illegible]
6M26M1:			Sand	2.4	4.2
Sandy soil	2.0	2.0	Sand and pea gravel	5.8	10.0
Sand	2.0	4.0	7L5R1—(E-6):		
Gravel	.5	4.5	Clay	2.4	2.4
6M28R1—(X-[illegible]):			Heavy black clay	.3	2.7
Clay	1.4	1.4	Clay, sand, and gravel	2.3	5.0
Sand and clay	[illegible]	4.3	Sand and small gravel	2.2	7.2
Sand and pea gravel	2.9	7.2	7L7A1—(E-[illegible]):		
6M33R1—(X-[illegible]):			Sand and clay	2.4	2.4
Clay and adobe	2.6	2.6	Sand	1.2	3.6
Sandy clay	[illegible]	4.0	Sand and gravel	[illegible]	8.0
Sand	1.1	[illegible]	7L22C1:		
Sand and pea gravel	[illegible]	[illegible]	Adobe	2.0	2.0
6N31D1:			Fine sand	2.4	[illegible]
Sandy clay	3.0	3.0	Gravel, medium	4.2	8.6
Very fine sand	6.0	[illegible]			
7K1N1—(E-[illegible]):					
Sandy soil	1.9	1.9			
Clay	1.8	3.7			
Clay, sand, and gravel	[illegible]	5.6			

TABLE [illegible].—*Logs of observation wells in the* [illegible] *area*—Continued

Well number and log	Thickness (feet)	Depth (feet)
[illegible]	[illegible]	[illegible]
[illegible]	3.2	[illegible]
[illegible]	.3	[illegible]
[illegible]	1.0	[illegible]
[illegible]	1.5	1.5
[illegible]	[illegible]	4.0
[illegible]	[illegible]	5.8
[illegible]	.7	.7
[illegible]	2.6	[illegible]
[illegible]	3.3	3.3
[illegible]	.7	4.0
[illegible]	1.3	5.3
[illegible]	3.8	9.1
[illegible]	8.4	8.4
7M12A1—(F-6):		
[illegible]	3.9	3.9
[illegible]	[illegible]	8.3
7M20C1—(X-16):		
[illegible]	1.4	1.4
[illegible]	2.2	3.6
[illegible]	.7	4.3
Clay	[illegible]	4.7
[illegible]	[illegible]	6.7
[illegible]	2.1	[illegible]
[illegible]	[illegible]	10.0
[illegible]	[illegible]	2.0
[illegible]	1.0	[illegible]
[illegible]	3.9	6.9
Clay and sand	.6	[illegible]
[illegible]	[illegible]	10.0
[illegible]	3.6	3.6
[illegible]	[illegible]	7.2
Sand and clay	.3	7.5
Sand, some clay	2.5	10.0
[illegible]	[illegible]	1.5
[illegible]	2.2	3.7
[illegible]	5.1	8.8
7N8N1—(F-7):		
[illegible]	2.0	10.0
[illegible]	[illegible]	2.0
[illegible]	2.0	[illegible]
Clay and thin layers	[illegible]	[illegible]
Sand	[illegible]	[illegible]
[illegible]	3.0	3.0
[illegible]	35.0	38.0
[illegible]	2.0	[illegible]
[illegible]	[illegible]	4.8
Loam with pebbles	2.5	2.5
[illegible]	15.0	[illegible]
Sandy soil	3.0	3.0
Adobe	1.5	[illegible]
[illegible]	2.0	3.5
Brown silt loam	[illegible]	[illegible]
[illegible]	[illegible]	5.1
[illegible]	[illegible]	5.5
Very fine sand, yel[illegible]	3.0	[illegible]
[illegible]	1.0	[illegible]

Well number and log	Thickness (feet)	Depth (feet)
[illegible]	[illegible]	4.0
[illegible]	[illegible]	2.0
[illegible]	1.5	3.5
[illegible]	1.5	4.0
[illegible] soil, brown	5.7	8.2
Dark green sand	.9	9.1
Sandy clay, loam	1.2	1.2
[illegible]	[illegible]	7.0
Clay gumbo	[illegible]	8.7
[illegible]	3.7	[illegible]
9M5K1—(X-12):		
Sand clay loam	1.0	1.0
[illegible]	4.2	5.2
[illegible]	[illegible]	8.0
[illegible]	3.9	11.9
[illegible]	1.7	1.7
[illegible]	1.9	3.6
[illegible]	[illegible]	5.6
[illegible]	[illegible]	7.6
[illegible]	2.4	10.0
[illegible]	[illegible]	1.9
[illegible]	5.4	7.3
Fine sandy clay	[illegible]	9.5
Clay loam, some sand	.7	[illegible]
Hard yellow sand and clay	[illegible]	3.0
[illegible]	[illegible]	5.4
[illegible]	3.1	[illegible]
Fine sand and a little clay	5.3	5.3
[illegible]	3.7	[illegible]
[illegible] clay	1.0	10.0
Clay and sand	.5	[illegible]
[illegible]	[illegible]	3.5
Coarse sand and pea [illegible]	.8	4.3
[illegible]	1.8	6.1
9M32R1—(X-7):		
Sand and pea gravel	3.4	3.4
[illegible]	1.6	5.0
Coarse sand and pea gravel	5.0	10.0
9N8M1:		
[illegible]	5.0	5.0
Clay	1.3	6.3
[illegible] table matter)	3.3	[illegible]
Sandy soil	4.0	[illegible]
Fine dark gray sand	[illegible]	[illegible]
[illegible]	3.0	3.0
[illegible]	2.0	5.0
Fine sand; dark gray	[illegible]	[illegible]
[illegible]	10.0	10.0
10K3D1:		
[illegible]	1.0	1.0
[illegible]	1.0	[illegible]
[illegible]	[illegible]	4.0
10K6N1:		
[illegible]	[illegible]	4.5
10K12A1:		
[illegible]	3.0	3.0
[illegible]	[illegible]	5.1
[illegible]	3.0	3.0
Sandy soil with peb[illegible]	1.0	1.0
Gravel	[illegible]	[illegible]
[illegible]	[illegible]	3.5
[illegible]	1.5	[illegible]

Well number and log	Thickness (feet)	Depth (feet)
10K23R1—(D-10):		
Sandy loam	[illegible]	[illegible]
Clay	[illegible]	[illegible]
Sand grading to pea [illegible]	2.9	[illegible]
Sandy loam, some gravel	2.3	[illegible]
Sandy clay	1.3	3.6
Sand and small gravel	[illegible]	6.2
10L14D1:		
Sandy soil	[illegible]	[illegible]
[illegible]	[illegible]	3.0
Medium coarse gravel	1.0	[illegible]
[illegible]	.4	.4
[illegible]	1.6	2.0
Large gravel, sand	4.1	[illegible]
Sand and gravel to [illegible]	4.5	4.5
Sand and small gravel	[illegible]	7.4
10L27A1—(D-5):		
Sandy loam	1.2	1.2
Sand and small gravel	1.8	3.0
[illegible]	3.5	6.5
Clayey sand and gravel	[illegible]	2.8
Sand and gravel	2.2	5.0
10L30A1—(D-8):		
Sandy loam	[illegible]	3.5
Sand	1.6	5.1
Sand and gravel	1.5	[illegible]
[illegible]	4.5	4.5
Sand	1.5	[illegible]
Sand and pea gravel	[illegible]	8.3
10L33R1:		
[illegible]	3.0	3.0
Coarse gravel	1.8	4.8
10M2A1:		
Fine sand	2.1	4.1
Gravel, medium	1.8	[illegible]
Sandy clay, green	1.9	[illegible]
Sand, little gravel	[illegible]	[illegible]
Sand and gravel	[illegible]	[illegible]
10M16D1—(X-5):		
Sand and small gravel	[illegible]	[illegible]
[illegible]	[illegible]	2.9
Clayey sand	.9	3.8
Sand and pea gravel	4.0	7.8
10M20D1—(X-3=D-1):		
Sandy loam and small gravel	3.0	3.0
Sand and gravel	3.5	6.5
10M32A1—(X-2):		
Sand and loam and pea gravel	[illegible]	[illegible]
[illegible]	[illegible]	4.2
Sand and pea gravel	[illegible]	[illegible]
[illegible] gravel	[illegible]	[illegible]
Sand and clay	.6	6.0
Sand and pea gravel	5.5	11.5
10M33R2—(C-2):		
Sand	[illegible]	8.2
[illegible]	[illegible]	8.5
10N31N1—(C-5):		
[illegible]	1.0	1.0
[illegible]	[illegible]	1.6
[illegible]	.5	[illegible]
[illegible]	3.1	5.2
11K01:		
Sandy soil	[illegible]	[illegible]
[illegible]	[illegible]	1.7
[illegible]	[illegible]	3.0
11K13R1:		
Sandy soil	1.5	[illegible]
[illegible]	3.0	4.5
11K16R1:		
[illegible]	[illegible]	[illegible]

Well number and log	Thickness (feet)	Depth (feet)
[illegible] and soil	[illegible]	[illegible]
Sandy soil	3.0	3.0
[illegible]	2.0	5.0
Sand soil	3.0	3.0
[illegible]	4.3	7.3
11L23D1:		
Sand and gravel	5.0	5.0
11L24A1:		
Sandy soil	1.5	1.5
[illegible]	4.3	[illegible]
11L30N1:		
Sandy soil	[illegible]	1.0
Gravel	3.0	4.0
11L33D1:		
Sandy soil	2.0	2.0
[illegible]	1.7	3.7
11L35D1:		
Sandy soil	2.8	[illegible]
[illegible]	2.0	4.8
Gravel, fine	1.5	6.3
Sandy soil	7.5	7.5
[illegible]	2.0	9.5
11M1D1—(C-4):		
Sand and some gravel	1.3	1.3
Clayey sand	1.6	[illegible]
Sand	1.5	4.4
Sand and small gravel	2.4	6.8
11M2D1—(C-3=Y-1):		
[illegible]	[illegible]	[illegible]
Brown sandy soil	[illegible]	[illegible]
11M10A1—(Y-2):		
Sand loam and small gravel	3.5	3.5
Sand and occasional [illegible]	[illegible]	6.0
[illegible]	4.0	10.0
11M13R1—(R-8):		
Silt and sand	[illegible]	2.0
Coarse sand	[illegible]	7.2
11M14D1—(Y-3):		
Sandy loam	3.0	3.0
[illegible]	7.0	10.0
Sandy soil	1.5	[illegible]
[illegible]	3.8	5.3
11M22R1—(Y-5):		
Sand and gravel	3.5	3.5
[illegible]	[illegible]	4.7
Sand and gravel	[illegible]	[illegible]
11M23D1—(Y-4=R-10):		
Fine sandy loam and small gravel	.8	3.5
Sand and pea gravel	4.7	8.2
Fine sand loam and a little gravel	4.2	[illegible]
Sand and gravel	3.8	8.0
Sandy soil	1.0	1.0
Fine sand	[illegible]	7.4
Sand loam and small gravel	[illegible]	3.6
Sand and pea gravel	[illegible]	[illegible]
Sand and gravel	[illegible]	9.1
[illegible]	[illegible]	2.0
Sand and pea gravel	4.0	6.0
Gravel	[illegible]	8.4
11M36R1—(A-3):		
Sand (sample)	6.6	6.6
Sand and gravel	.4	[illegible]
Sand	3.0	10.0
11N3R1—(C-9):		
[illegible]	[illegible]	4.0
[illegible]	[illegible]	7.8
Fine sand	[illegible]	2.4
[illegible]	[illegible]	7.2
[illegible]	[illegible]	[illegible]

TABLE 1.—*Logs of observation wells in the closed basin area*—Continued

Well number and log	Thickness (feet)	Depth (feet)
11N5N1—(C-6):		
Sand	[illegible]	1.5
Sandy clay	1.3	2.8
Sand, slightly clayey	[illegible]	4.2
Clay	.6	4.8
Coarse sand	[illegible]	[illegible]
[illegible]		
Clay	4.0	4.0
Clay, sand	[illegible]	5.5
Sand	1.1	[illegible]
11N13D2—(C-11):		
[illegible]	1.2	1.2
Sand clay	1.8	3.0
Sand; some clay	3.7	6.7
11N14D[illegible]:		
Fine sand	4.0	4.0
Sand and [illegible]	2.0	6.0
Clay	[illegible]	6.6
Sand	[illegible]	10.0
11N1[illegible]N1—(R-7):		
Sand	3.5	3.5
Coarse sand	3.5	7.0
11N22E1—(R 5):		
Clay	4.0	4.0
Clay, sandy	.5	4.5
11N2[illegible]A1—(R-[illegible]) [illegible] moved in [illegible]		
Sand	1.5	1.5
Sandy clay	3.0	4.5
11N26B1—(R-2):		
Sandy	4.0	[illegible]
11N26D1—(R-3):		
Clayey sand	3.5	3.5
Sand	2.3	5.8
[illegible] hardpan	.5	6.3
Fine silty sand	.7	7.0
11N27B1—(R-[illegible]):		
Sand, some clay on top	3.5	3.5
Hardpan	.5	[illegible]
Fine sand	.5	4.5
11N[illegible]N1—(A-[illegible]):		
Sand	.9	[illegible]
Clay	.9	1.8
Sand	3.9	5.7
Sand and fine gravel	3.7	9.4
11N33R1—(A-6):		
Clay loam	.5	.5
Clay	1.9	2.4
Sand and clay	.9	3.3
Sand	.7	4.0
Fine clayey sand	2.2	6.2
Sand	1.9	8.1
11N34R1—(A-7):		
Clay loam	1.5	1.5
Clay	1.7	3.2
Sand and some gravel	6.8	10.0
11N35L1—(S-1):		
Sand	4.0	4.0
11N35Q1—(S-2):		
Sand?	4.0?	4.0?
11Q7R1—(C-13):		
Sand	1.5	1.5
Sandy clay	1.5	3.0
Slightly clayey sand	4.0	7.0
Sand	3.0	10.0
11Q16H1—(C-15):		
Fine sand	3.5	3.5
Hardpan?	.1	3.6
Sand	4.0	7.6
11Q17G2—(C-14):		
Sandy clay	2.5	2.5
Sand	7.5	10.0
11Q18D1—(C-12):		
Fine sandy clay	2.8	2.8
Sand	1.0	3.8
Sand [illegible]	.1	3.9
Green sandy clay	3.1	7.0
Fine sand	1.1	8.1
11Q[illegible]N1—(A-[illegible]):		
Sandy clay	[illegible]	.5
Clay	4.7	5.2
Sandy clay	4.8	10.0
11Q32N1—(A-10):		
Sand, clayey	6.0	6.0
Silty sand	4.0	10.0
11Q33N1—(A-11):		
Sand	10.0	[illegible]
12K8A1:		
Sandy soil with pebbles	1.0	1.0
Coarse gravel	2.5	3.5
12K11A1—(B-12):		
Sandy loam, small gravel	2.0	2.0
Sand and gravel	2.5	4.5
Sand and small gravel	.5	5.0
12K[illegible]A[illegible]—(B-[illegible]):		
Sandy loam	1.5	[illegible]
Large gravel	.4	1.9
Sand and a little gravel	2.7	4.6
Gravel and sand	2.4	7.0
12K13R1:		
Adobe	[illegible]	2.0
Sand, medium to coarse	[illegible]	3.8
12K15N1:		
Adobe soil with pebble	2.0	2.0
Sandy adobe soil	1.0	3.0
Gravel	1.0	4.0
12L1R1—(B-5):		
Sandy loam, small gravel	4.8	4.8
Sand	2.6	7.4
Sand and gravel	[illegible]	8.7
12L2N1—(B-7):		
Sandy loam	2.5	2.5
Sand	2.5	5.0
Sand and fine gravel	3.0	8.0
12L2R1—(B-[illegible]):		
Sandy loam	[illegible]	1.0
Fine sand	2.0	3.0
Coarse sand	4.5	7.5
12L4R1—(B-8):		
Sandy loam and small gravel	1.5	1.5
Sand and pea gravel	4.2	5.7
Sand and gravel	1.9	7.6
12L5R1—(B-9):		
Sandy loam	3.5	3.5
Sand and gravel, small	3.8	7.3
Coarse sand and gravel	1.8	9.1
12L7A3—(B-10):		
Sand loam and small gravel	2.0	2.0
Sand and gravel	[illegible]	5.0
Sand and small gravel	2.2	7.2
12L15R1:		
Sandy soil	1.0	1.0
Fine sand	3.3	4.3
12L17R1:		
Adobe	2.0	2.0
Coarse sand	3.0	5.0
12L26N1:		
Adobe	2.0	2.0
Fine sand	.8	2.8
Coarse sand	2.4	5.2
12L29R1:		
Sandy soil	1.0	1.0
Coarse gravel	3.0	4.0
12M3R1—(Y-8)—(B-1):		
Fine sand, occasional small gravel	5.5	5.5
Sand and gravel	1.0	6.5
Sand and some gravel	2.4	8.9
12M5N2—(B-4):		
Fine sandy loam	3.0	3.0
Sandy loam, some gravel	3.0	6.0
Sand and pea gravel	2.8	8.8
12M8A1—(B-3):		
Fine sandy loam	3.0	3.0
Sand	3.8	6.8
Sand and small gravel	1.8	8.6
12M9A2—(B-2):		
Fine sandy loam	2.5	2.5
Sandy loam	[illegible]	7.0
Sand and gravel	3.0	10.0
12M10R1—(Y-9):		
Sandy loam, small gravel	6.0	6.0
Sand, occasional gravel	4.0	10.0
12M13A1:		
Fine silt	[illegible]	5.4
12M14N1—(Y-10):		
Fine clayey sand	3.2	3.2
Sand and pea gravel	1.9	5.1
Sand and gravel	[illegible]	5.8
Sand and small gravel	[illegible]	[illegible]
12M16N1:		
Sandy soil	[illegible]	4.8
Fine sand	1.9	6.7
Medium coarse gravel	2.3	9.0
12M19D1:		
Sandy silt	4.3	4.3
Medium gravel	2.0	6.3

TABLE 1.—*Logs of observation wells in the closed basin area*—Continued

Well number and log	Thickness (feet)	Depth (feet)
12M23N1—(Y-11):		
Sandy loam		
Sand	[illegible]	[illegible]
Sand and small gravel	[illegible]	[illegible]
12M26N1—(Y-12):		
Sandy loam and pea gravel	3.6	3.6
Sand	[illegible]	8.8
12M29R1:		
Sandy clay soil	1.0	[illegible]
Fine sand	[illegible]	[illegible]
12M30N1:		
Adobe	4.0	[illegible]
Fine sand	2.5	[illegible]
12M35N1—(Y-13):		
Clay	2.8	2.8
Sand	2.2	5.0
Sand and occasional gravel	3.7	8.7
12N1D1—(A-8):		
Clay, some sand	6.7	6.7
Clayey sand	3.3	10.0
12N6A1—(A-4):		
Sandy loam	1.5	[illegible]
Sand	1.9	3.[illegible]
Sand and clay	.4	[illegible]
Sand and fine gravel	4.4	[illegible]
12N2[illegible]N1:		
Wind-blown soil	1.5	1.5
Fine sand, organic matter	1.9	3.4
Sand, rusty color	1.4	4.8
Sand and silt	1.5	6.3
12N[illegible]R1:		
Adobe	[illegible]	6.0
Fine sand	2.0	8.0
12Q[illegible]L2:		
Wind-blown sand	[illegible]	1.0
Sand with stiff clay	1.1	2.1
Medium fine sand	.9	3.0
Medium fine sand with iron oxide concretions	.5	[illegible]
Clay and sand	.5	4.0
Fine sand	4.0	[illegible]
12Q18D1:		
Clay	3.5	3.5
Fine sand		4.0
13M6N1:		
Sandy soil	2.0	2.0
Gravel	5.5	7.5
13M11D1—(Y-14):		
Sandy clay	2.4	2.4
Fine sand, clayey	.7	3.1
Clay	.7	3.8
Sand	[illegible]	[illegible]
13M14A1—(Z-2):		
Sandy loam	1.4	1.4
Clayey sand	4.6	6.0
Sand	4.0	10.0
13M14D1—(Z-1=Y-15):		
Fine sandy loam	2.0	2.0
Clayey sand	1.2	3.2
Sand	6.8	10.0
[illegible]		
Clay, loam	2.3	2.3
Sand and gravel	2.1	[illegible]
Sand and pea gravel	[illegible]	
13M17H1:		
Clay soil	3.0	3.0
Coarse gravel	1.8	4.8
13M22R1—(Y-17):		
Clay loam	1.8	1.8
Clay	1.8	[illegible]
[illegible]	2.7	[illegible]
Sand	1.7	8.0
Sand and small gravel	2.0	10.0
13M35D1—(Y-18):		
Clay loam	2.0	2.0
Clay and pea gravel	2.0	[illegible]
Clay sand and gravel	1.5	
Sand and gravel	1.5	[illegible]
13N2D1:		
Adobe	2.0	2.0
Very fine sand	[illegible]	7.0
Fine sand	1.5	8.5
13N[illegible]R1—(Z-[illegible]):		
Clay loam	1.3	1.3
Sand	2.0	3.3
Clayey sand	1.5	[illegible]
Clay	2.2	7.0
Sand and clay	2.0	[illegible]
Sand clay and small gravel	1.0	10.0
13N10R1—(Z-7):		
Sand and clay, varying degrees	6.3	6.3
Fine sand	3.9	10.2
Sandy clay	1.3	11.5
Sand	1.0	12.5
13N15D1—(Z-6):		
Clay loam	.5	.5
Clay	1.3	1.8
Sand	1.1	2.9
Clay	1.3	4.2
Sand	2.0	6.2
Sand	3.8	10.0
13N16D1—(Z-5):		
Sand and clay	3.3	3.3
Sand	3.2	6.5
Clay	.4	6.9
Sand	1.3	8.2
Sandy clay	3.8	12.0
13N18D1—(Z-3):		
Clay loam	1.5	1.5
Clay	1.9	3.4
Clayey sand	.6	4.0
Streaked clay and sand	2.2	6.2
Sand	2.8	9.0
13Q26N2:		
Wind-blown sand	.5	.5
Brown clay, hardly any sand	[illegible]	1.2
Fine loose sand	[illegible]	2.7
Medium sand with clay matrix	2.8	5.5
14N9R1:		
Sand and silt	2.5	2.5
Clay, some sand	1.9	4.4
Gravel, medium to coarse	1.4	5.8

In order to study the character and distribution of the material of the shallow valley fill in the closed basin area, table 3 has been prepared, separating the material reported in the observation-well logs into four groups, as follows: (1) Clay or loam, (2) fine sand, (3) medium or coarse sand, and (4) gravel. This grouping represents only in a general way the distribution of the material, as the classification of the material depended largely upon the individual boring the well. However, it is a rough index of the material composing the upper part of the shallow valley fill. In the table the material of the groups is expressed as a percentage of the combined length of all the observation wells for which logs

[illegible] in a township. No computations were [illegible] where the material was represented by less than three well logs in a township. A final grouping was made of the area as a whole, using all available well logs. In this final summation, 186 well logs were used, representing [illegible] feet of hole.

None of the observation wells penetrated the entire thickness of the shallow valley fill but only 1 to 2 feet below the water table, usually to depths of only 10 feet or less. Thus the figures represent only the distribution of the material down to and a little below the water table.

The table shows quite clearly the preponderance of coarse material on the Rio Grande alluvial fan and along the edge of the valley floor. Similarly, it shows the large amount of fine material, as clay or loam and fine sand, in the central part of the valley. This is especially true in the trough of the valley, as, for example, T. 39 N., R. 11 E., lying immediately south of San Luis Lake. In this township 80.5 percent of the alluvium was classified as fine material—that is, clay, loam, or fine sand. In T. 39 N., R. 8 E., on the Rio Grande alluvial fan and 18 miles west of the township just described, only 39.0 percent of the material is fine, whereas 61.0 is coarse. For the area as a whole there is more fine material than coarse, the ratio being 54.5 percent fine and 45.5 percent coarse. This is to be expected, however, as the alluvial fans occupy considerably less than half of the valley floor.

Laboratory analyses of the materials.—In order to form some concrete conception of the physical and water-bearing properties of the material in the shallow valley fill, 22 samples were analyzed in the hydrologic laboratory of the Geological Survey, at Washington, D. C. These samples were taken from 12 wells located on the valley floor and distributed over the closed basin area. The results of the analysis, together with the field classification of the material are given in tables 4 and 5.

TABLE 2.—*Logs of observation wells in the Carmel-Bowen or [illegible] area*

[illegible]

[illegible]	[illegible]	[illegible] (feet)	[illegible]	Thickness (feet)	Depth (feet)
[illegible]			[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.5
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.0
[illegible]			[illegible]		
[illegible]			[illegible]	1.7	1.7
[illegible]	8.5	[illegible]	[illegible]	[illegible]	3.6
[illegible]			[illegible]		
[illegible]		[illegible]	[illegible]	1.5	[illegible]
[illegible]			[illegible]	[illegible]	3.4
[illegible]			[illegible]		
[illegible]		[illegible]	[illegible]	1.5	[illegible]
[illegible]	[illegible]	[illegible]	Gravel, [illegible] with [illegible] scattered pebbles	[illegible]	3.4
[illegible]			[illegible]		
[illegible]	[illegible]	2.6	[illegible]	[illegible]	[illegible]
Coarse pebbly gravel			Gravel, large pebbles	3.5	[illegible]

TABLE 2.—*Logs of observation wells in the closed basin area*—Continued

Well [illegible] and log	Thickness (feet)	Depth (feet)
[illegible]:		
Brown soil	2.0	2.0
[illegible]	[illegible]	3.3
Gravel with [illegible]	[illegible]	[illegible]
14K25N1:		
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]:		
[illegible]	2.6	2.6
[illegible] scattered [illegible]	1.9	4.5
[illegible]:		
[illegible]	1.4	1.4
Gravel with [illegible] and small [illegible]	2.4	[illegible]
[illegible]:		
[illegible]	4.5	4.5
Coarse gravel with [illegible]	[illegible]	[illegible]
[illegible]:		
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
Fine sand	[illegible]	[illegible]
[illegible]:		
[illegible]	1.5	1.5
[illegible]	7.0	8.5
[illegible]	2.0	10.5
[illegible]:		
[illegible]	3.0	3.0
Coarse sand	1.7	4.7
[illegible]	2.2	[illegible]
[illegible]:		
Adobe	3.0	3.0
[illegible]	[illegible]	4.5
[illegible]:		
[illegible]	3.0	3.0
[illegible]	1.8	[illegible]
Sandy clay	1.3	6.1
14L31P1:		
[illegible]	[illegible]	1.5
Fine sandy soil	[illegible]	5.2
Gravel, medium to [illegible]	.4	[illegible]
14L34N1:		
[illegible]	[illegible]	2.5
[illegible]	1.5	[illegible]
[illegible]:		
[illegible]	2.0	[illegible]
Gravel	1.5	3.5
[illegible]:		
[illegible]	1.0	1.0
Sandy soil	[illegible]	[illegible]
Fine sand	[illegible]	[illegible]
[illegible]:		
Sandy soil	5.5	[illegible]
14M19N1:		
[illegible]	3.0	[illegible]
[illegible]	2.0	[illegible]
[illegible]	3.0	[illegible]
14M21N1:		
[illegible]	2.0	2.0
Fine gravel	1.0	3.0
[illegible]:		
[illegible]	3.0	3.0
[illegible]	2.0	5.0
[illegible]:		
[illegible]	3.0	3.0
[illegible]	1.5	4.5
[illegible]	[illegible]	7.0
14N31M1:		
[illegible]	1.5	1.5
[illegible]	1.0	2.5
[illegible]	[illegible]	[illegible]
[illegible]:		
[illegible]	[illegible]	[illegible]
Gravel, medium to [illegible]	[illegible]	[illegible]
15K1P1:		
Brown soil with scattered [illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	.3	5.3
15K1P2:		
[illegible]	[illegible]	4.0
[illegible]	[illegible]	[illegible]
Gravel, coarse		
15K3B1:		
[illegible] pebbles and small [illegible]	[illegible]	5.0
[illegible]:		
Brown soil with large scattered pebbles and small boulders	[illegible]	[illegible]
[illegible]:		
[illegible] with [illegible]	5.2	[illegible]
[illegible]:		
[illegible] scattered pebbles	[illegible]	1.6
Gravel, medium to [illegible]	.5	2.1
[illegible]:		
[illegible]	3.2	3.2
[illegible] scattered pebbles	[illegible]	5.1
[illegible]:		
[illegible] gravel	23.0	23.0
15L13A1:		
[illegible]	2.0	2.0
[illegible]	.5	2.5
15L14D1:		
[illegible]	2.0	2.0
[illegible]	1.5	3.5
15L16D1:		
[illegible]	3.0	3.0
Gravel, medium to [illegible]	1.4	4.4
15L17D1:		
[illegible]	.9	[illegible]
[illegible]	4.3	5.2
Gravel and boulders	1.8	7.0
[illegible]:		
[illegible] with large pebbles and boulders scattered [illegible]	3.8	3.8
Gravel with large pebbles and cobbles	[illegible]	5.0
[illegible]:		
[illegible]	3.8	3.8
Gravel, medium to [illegible]	[illegible]	4.3
[illegible]:		
[illegible]	[illegible]	[illegible]
Gravel, medium to [illegible]	[illegible]	4.7
15L30G1:		
[illegible]	1.4	1.4
[illegible]	3.6	5.0
[illegible]:		
Brown soil and adobe	4.8	4.8
[illegible]	[illegible]	6.8
Gravel, medium to coarse	1.6	[illegible]
15L35R1:		
[illegible]	[illegible]	5.0
Brown sandy soil (no gravel)	[illegible]	[illegible]
[illegible]:		
Adobe	3.0	3.0
[illegible]	[illegible]	5.0
Gravel	1.5	[illegible]
Sandy clay	[illegible]	7.0
[illegible]:		
[illegible]	[illegible]	[illegible]
[illegible]:		
[illegible]	[illegible]	[illegible]
[illegible]:		
[illegible]	[illegible]	4.0
[illegible]:		
[illegible]	1.0	1.0
[illegible]	2.0	3.0
[illegible]:		
[illegible]	[illegible]	5.0
[illegible]	[illegible]	5.7
[illegible]:		
[illegible]	3.0	3.0
[illegible]	[illegible]	4.5
16L5D1:		
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	6.5
[illegible]	[illegible]	[illegible]
[illegible]:		
Adobe	[illegible]	[illegible]
[illegible]:		
[illegible]	[illegible]	[illegible]
Fine sand	1.5	[illegible]

TABLE 3.—*Composition of material in the shallow valley fill of the closed basin area, based on percentage of total footage in logs of observation wells in the several townships*

Coordinate number	Township and range	Number of well logs	Clay or loam	Sand: Fine	Sand: Medium or coarse	Gravel
6L	T. 44 N., R. 9 E.	[illegible]	[illegible]	32.5	2.5	9.5
6M	T. 44 N., R. 10 E.	8	55.0	20.0	12.0	13.0
7K	T. 43 N., R. 8 E.	11	47.0	24.0	11.0	18.0
7L	T. 43 N., R. 9 E.	7	30.0	13.0	34.0	23.0
7M	T. 43 N., R. 10 E.	11	33.5	33.5	32.0	1.0
8J	T. 42 N., R. 7 E.	4	[illegible]	6.5		78.0
9K	T. 42 N., R. 8 E.	3	31.0	41.0	28.0	-------
9L	T. 42 N., R. 9 E.	4	47.0	36.0	8.5	8.5
9M	T. 42 N., R. 10 E.	9	23.0	38.0	26.0	13.0
9N	T. 1 S., R. 1 W.	3	36.0	64.0		
10K	T. 41 N., R. 8 E.	8	36.5	32.0	11.0	20.5
10L	T. 41 N., R. 9 E.	8	22.0	16.0	29.0	33.0
10M	T. 41 N., R. 10 E.	8	19.0	14.5	40.5	26.0
11K	T. 40 N., R. 8 E.	5	16.5	9.5	..	74.0
11L	T. 40 N., R. 9 E.	8	23.5	39.0	9.5	28.0
11M	T. 40 N., R. 10 E.	14	15.5	24.5	46.5	13.5
11N	T. 40 N., R. 11 E.	16	26.0	28.0	41.0	5.0
11Q	T. 40 N., R. 12 E.	7	[illegible]	26.5	48.0	-------
12K	T. 39 N., R. 8 E.	[illegible]	28.0	11.0	20.0	41.0
12L	T. 39 N., R. 9 E.	10	20.5	20.5	38.5	20.5
12M	T. 39 N., R. 10 E.	14	29.0	31.5	27.0	12.5
12N	T. 39 N., R. 11 E.	4	43.0	37.5	12.5	7.0
13M	T. 38 N., R. 10 E.	8	29.0	20.0	34.0	17.0
13N	T. 38 N., R. 11 E.	6	34.5	45.5	19.0	1.0
	Total area	180	28.5	26.0	28.5	17.0

[1] Baca Grant.

Permeability of the materials. The hydraulic permeability of a rock is its capacity for transmitting water under pressure.[10] A measure of this capacity, as used by the United States Geological Survey, is called the "coefficient of permeability", which is defined as the rate of flow, in gallons a day, through a square foot of cross section under a hydraulic gradient of 100 percent, at a temperature of 60° F. The coefficient of permeability can also be defined as the quantity of water, in gallons a day, that is conducted laterally through each mile of the water-bearing bed under investigation (measured at right angles to the direction of flow) for each foot of thickness of the bed and for each foot per mile of hydraulic gradient.[11]

The coefficients of permeability of water-bearing materials range widely. Materials tested in the hydrologic laboratory of the United States Geological Survey at Washington, D. C. were found to have coefficients of permeability ranging from 0.001 to 90,000 [12]—that is, the greatest permeability was 90,000,000 times the least. As is shown in the preceding tables, the material in the shallow valley fill ranges of the San Luis Valley widely from silt to coarse gravel, and there is likewise a wide range in the permeability of the material.

The transmissibility of an aquifer, as defined by Theis,[13] is the average coefficient of permeability, multiplied by the thickness of the aquifer.

In addition to the laboratory determinations shown in the table, the coefficient of permeability was determined in one locality in the field by methods developed by Thiem [14] and by Theis.[15]

The Thiem method for determining permeability of water-bearing materials consists of pumping a well and observing the decline of the water table in nearby observation wells. Thiem's formula for computing the

[10] Meinzer, O. E., The occurrence of ground water in the United States, U. S. Geol. Survey, Water-Supply Paper 489, p. 28, 1923.

[11] Stearns, N. D., Laboratory tests on physical properties of water-bearing materials: U. S. Geol. Survey Water-Supply Paper 596, p. 148, 1927.

[12] Meinzer, O. E., Movements of ground water: Am. Assoc. Petroleum Geologists Bull., vol. 20, no. 6, p. 710, 1936.

[13] Theis, C. V., The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys Union Trans., p. 520, 1935.

[14] Thiem, G., Hydrologische Methoden, Leipzig, 1906.

[15] Op. cit., p. 522.

TABLE 4.—*Physical properties of material from the shallow valley fill in the closed basin area, San Luis Valley, Colorado*

Well no.	Depth (feet)	Field classification of material	Apparent specific gravity	Porosity (percent)	Moisture equivalent (percent by volume)	Specific retention (percent by volume)	Specific yield (porosity minus specific retention by volume)	Permeability
9M2C1	0-4.5	Clay, slightly sandy	1.39	48.7	17.5	16.4	32.3	[illegible]
	4.5-5.3	Sand	1.44	47.0	[illegible]	10.8	36.2	90
10K12A1	0-3.0	Sandy loam	1.44	46.5	15.3	14.7	31.8	20
	3.0-4.5	Sand and gravel	1.55	40.4	8.5	9.0	31.4	650
10M2A1	0-2.2	Clay, slightly sandy	1.31	[illegible]	43.7	41.6	[illegible]	[illegible]
	2.2-5.0	Coarse sand	1.39	40.2	[illegible]	[illegible]	7.8	(2)
	5.0-5.8	Very coarse sand	1.52	41.9	6.6	7.3	[illegible]	900
10L23D1	3.0	Coarse sand and gravel	1.87	(3)	(3)			1,500
11M1D1	0-5.0	Sandy gravel	1.65	36.9	12.2	12.4	[illegible]	[illegible]
11M26R1	5.0-5.7	Sand, some gravel	1.74	34.3	9.4	10.1	24.2	85
11N3R1	0-2.5	Sand	1.37	48.0	12.3	12.2	35.8	180
	2.5-4.0	Adobe, slightly sandy	1.43	47.8	[illegible]			(2)
	4.0	Sand, little clay	1.49	43.7	18.0	17.0	26.7	80
12K34A1	4.0-4.5	Sand and gravel	1.75	(3)	(3)			600
12N25N1	3.4-4.8	Fine sand	1.38	47.9	18.2	16.8	31.1	[illegible]
	4.8-6.6	Sand and silt	1.58	39.3	9.6	10.1	29.2	[illegible]
12Q[illegible]	1.0-2.1	Sand and clay	1.20	55.3	25.7	22.5	32.8	[illegible]
	2.1-3.0	Fine sand	1.43	[illegible]	27.7	24.3	[illegible]	65
13M11D1	2.2-2.8	Adobe	1.25	53.4	25.8	22.6	[illegible]	(2)
	2.8-4.5	Sand	1.40	[illegible]	9.7	9.9	[illegible]	60
13Q20N2	1.5-2.2	Fine sand	1.35	48.8	26.9	23.6	[illegible]	(2)
	2.7-5.5	Sand and clay	1.45	46.3	23.2	20.9	25.4	1

[1] Based on relation of moisture equivalent to specific retention after 400 days' drainage. Piper, A. M., Thomas, H. E., and Robinson, T. W. Ground-water hydrology of the Mokelumne area, California (U. S. Geol. Survey typewritten report, Oct. 30, 1935).

[2] Less than 1.

[3] Too coarse to determine porosity and moisture equivalent.

coefficient of permeability as expressed by Wenzel [16] is written in the following form:

$$P=\frac{527.7\,q\,\log_{10}(a_1/a)}{m\,(s-s_1)}$$

in which P = the coefficient of permeability;
q = rate of pumping, in gallons a minute;
a and a_1 = distances of two observation wells from the pumping well, in feet;
m = average saturated thickness (at a_1 and a) of the saturated part of the water-bearing bed, in feet;
s and s_1 = draw-downs at the two observation wells, in feet.

A pumping test was made near Monte Vista, Colo., during the summer of 1936, on an irrigation well owned by G. E. Oxley, about 6½ miles northeast of Monte Vista, in the NW¼ sec. 13, T. 39 N., R. 8 E. This well, no. 12K13D1, is located on the south side and well toward the base of the Rio Grande alluvial fan. There were four other irrigation wells within a mile of the pumped well, but none of them were operated during the period of the test or for several days before the test was begun.

The pumped well is about half a mile south of an east-west irrigation canal (the Prairie ditch). As water was flowing in the canal for several months preceding and also during the period of the test it is believed that any seepage from the canal did not affect conditions during the test. The slope of the water table was, from west to east—that is, from well 12K14A1 to well 12K13D3.

The pumped well was drilled in 1934 to a depth of 54 feet and is 20 inches in diameter. Concrete to a depth of 2 feet had been placed as a seal in the bottom of the hole, thus reducing the effective depth to 52 feet. The measured depth at the time of the test was 49 feet, indicating that 3 feet of the hole had filled in. The well was cased with 17 joints of galvanized-iron casing, perforated from 19 feet to the bottom, and gravel packed on the outside from top to bottom. Mr. Oxley reported that in drilling the well, coarse sand and gravel were penetrated to a depth of 50 feet, where clay was struck. While sinking the observation wells, it was noted that the sand and gravel became coarser with depth.

Four observation wells were sunk in the vicinity of the pumped well, two on an east-west line, and two on a north-south line through the well and on opposite sides. All the observation wells were 1 inch in diameter and three of them were fitted with 24-inch screen drive points. These wells were driven into the saturated sand and gravel to such depth that the water table during pumping would not drop below the bottoms of the wells. Each of the observation wells was developed by pumping with a pitcher pump until the water discharged was clear, indicating that the ground water had free access to the well and that the water level in the well showed the level of the water table. Definite points were established at each well from which measurements of the depth to the water level could be made. In order to determine the relative differences in altitude of the measuring point of the wells, instrumental levels were run from an assumed datum of 100 feet at the measuring point of the pumped well to all of the observation wells.

TABLE 5.—*Mechanical analysis of material from the shallow valley fill in the closed basin area, San Luis Valley, Colo.*

Well no.	[illegible]	[illegible]	[illegible]	0.50–[illegible]	0.25–[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		2.4	21.3	[illegible]	[illegible]	9.5
	[illegible]	[illegible]	2.9	14.7	[illegible]	29.1	9.2
10K12A1....	[illegible]	[illegible]	26.1	[illegible]	7.6	2.2	3.1
	3.0–4.5	53.0	[illegible]	13.2	5.9	[illegible]	[illegible]
[illegible]	[illegible]	5.6	23.0	26.2	19.0	13.0	13.2
	2.2–5.0	10.9	23.3	32.3	18.9	[illegible]	4.8
	5.0–5.8	[illegible]	45.4	[illegible]	7.2	2.9	.9
[illegible]	3.0	75.7	9.0	9.5	[illegible]	.8	.4
[illegible]	0–5.0	[illegible]	17.9	28.3	17.9	9.3	6.6
[illegible]	5.0–5.7	[illegible]	[illegible]	[illegible]	14.2	6.8	3.3
11N3R1.....	[illegible]	[illegible]	3.8	40.1	40.6	[illegible]	5.0
	[illegible]	[illegible]	8.8	[illegible]	[illegible]	[illegible]	15.4
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.6
12K14A1....	[illegible]	[illegible]	13.6	18.3	[illegible]	[illegible]	.5
[illegible]	[illegible]	[illegible]	20.6	[illegible]	[illegible]	[illegible]	4.3
	4.8–6.6	3.2	17.2	32.8	[illegible]	[illegible]	[illegible]
[illegible]	1.0–2.1	[illegible]	14.2	30.0	[illegible]	[illegible]	4.5
	[illegible]	[illegible]	3.2	23.2	[illegible]	[illegible]	6.8
[illegible]	[illegible]	[illegible]	27.0	27.8	[illegible]	[illegible]	12.2
	[illegible]	[illegible]	[illegible]	49.4	15.2	1.9	1.3
[illegible]	[illegible]	[illegible]	11.6	11.0	[illegible]	[illegible]	11.4
	[illegible]	[illegible]	15.8	27.7	24.9	15.4	[illegible]

TABLE 6.—*Number, depth, altitude, and location of wells used in pumping test*

Well no.	[illegible] point (feet)	[illegible] (+) or below (−) land surface (feet)	[illegible] point; as- [illegible] point of pumped well [illegible]	[illegible] in feet and direction from pumped well
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	15.2	[illegible]	101.00	100 north.
[illegible]	8.9	+.1	[illegible]	[illegible]
12K13D1	13.5	+.4	100.06	[illegible]
12K14A1	11.9		[illegible]	[illegible]

The test was started at 9:27 on the morning of September 3. During the 3 days preceding the test, measurements were made of depth to water in all of the wells in order to determine the static level of the water table, and a round of measurements was made a few minutes before the pump started. All measurements were made with a steel tape, graduated to

[16] [illegible]

TABLE 7.—*Location and depth to water levels, in feet, below measuring points, in observation wells used in the pumping tests*

12K13D1 Pumped well		12K13D2 [illegible] feet north of pumped well		12K13D3 140 feet east of pumped well		12K13D4 [illegible] feet south of pumped well		12K[illegible] 60 feet west of pumped well	
Time	Depth to water (feet)	Time	Depth to water (feet)	Time	Depth to water (feet)	Time	Depth to water (feet)	Time	Depth to water (feet)
AUGUST 31									
	4.81		[illegible]		[illegible]		[illegible]		[illegible]
SEPTEMBER 1									
	4.78		[illegible]		4.72		[illegible]	[illegible]	[illegible]
	4.78		5.77		4.71		4.79	3:34 p. m.	[illegible]
SEPTEMBER 2									
11:12 a. m.	4.78	[illegible]	5.77	11:09 a. m.	4.72	11:14 a. m.	[illegible]	[illegible]	[illegible]
SEPTEMBER 3									
[illegible]	[illegible]	[illegible]	5.77	[illegible]	4.81	[illegible]	4.13	[illegible]	4.61
9.27 a. m.	(1)	10:02 a. m.	6.34	10:04 a. m.	5.23	10:05 a. m.	5.86	9:59 a. m.	5.03
9:40 a. m.	17.84	10:26 a. m.	6.44	10.27 a. m.	5.35	[illegible]	6.06	10.24 a. m.	[illegible]
9:42 a. m.	17.82	10:49 a. m.	6.53	10:50 a. m.	5.46	10:52 a. m.	6.22	10:47 a. m.	5.28
9:43 a. m.	[illegible]	11:12 a. m.	6.59	11:15 a. m.	5.56	11:15 a. m.	6.34	11:10 a. m.	5.39
10:08 a. m.	17.95	11:34 a. m.	6.66	11:35 a. m.	5.62	11:37 a. m.	6.47	11:31 a. m.	5.48
10:32 a. m.	17.93	12.00 m.	6.74	12:01 p. m.	5.70	12:03 p. m.	6.58	11:58 a. m.	[illegible]
10:54 a. m.	18.09	[illegible]	6.82	12:33 p. m.	5.82	[illegible]	6.69	12:29 p. m.	5.69
11:16 a. m.	18.15	[illegible]	6.94	1:10 p. m.	5.91	1:12 p. m.	6.80	1:07 p. m.	5.81
11:19 a. m.	18.26	[illegible]	6.97	1:36 p. m.	5.98	[illegible]	6.89	1:33 p. m.	5.85
[illegible]	18.27	[illegible]	7.09	2:26 p. m.	6.09	2:28 p. m.	7.02	2.22 p. m.	5.97
[illegible]	18.23	[illegible]	7.15	3:05 p. m.	6.16	3:06 p. m.	7.09	[illegible]	6.07
[illegible]	18.45	[illegible]	7.21	3:38 p. m.	6.22	[illegible]	7.16	3:34 p. m.	6.13
1:41 p. m.	18.41	4:19 p. m.	7.27	4:21 p. m.	6.28	[illegible]	7.23	4:17 p. m.	6.20
[illegible]	18.63	5:01 p. m.	7.33	[illegible]	6.32	[illegible]	7.30	5:00 p. m.	6.28
3:09 p. m.	18.59	[illegible]	7.36	5:34 p. m.	6.37	[illegible]	7.34	5:31 p. m.	6.32
[illegible]	18.78	[illegible]	7.41	[illegible]	6.42	6:07 p. m.	7.36	6:01 p. m.	6.36
[illegible]	18.7								
5:13 p. m.	18.77								
[illegible]	18.7								
6:10 p. m.	18.79								
[illegible]	18.76								
SEPTEMBER 4									
8:20 a. m.	19.52	8:02 a. m.	7.77	8:05 a. m.	6.71	8:07 a. m.	7.67	8:00 a. m.	6.75
8:37 a. m.	19.31	[illegible]	7.80	8:56 a. m.	6.78	8:59 a. m.	7.77	8:53 a. m.	6.83
8:41 a. m.	19.15	[illegible]	7.88	9:58 a. m.	6.83	10:00 a. m.	7.85	9:52 a. m.	[illegible]
[illegible]	19.32	10:54 a. m.	7.93	10:56 a. m.	[illegible]	10:58 a. m.	[illegible]	[illegible]	6.97
[illegible]	19.33	[illegible]	7.96	11:57 a. m.	6.91	11:59 a. m.	7.97	[illegible]	7.01
11:01 a. m.	19.44	[illegible]	8.00	12:57 p. m.	[illegible]	[illegible]	8.01	[illegible]	7.05
12:02 p. m.	19.49	1:53 p. m.	8.02	[illegible]	6.98	1:57 p. m.	8.04	1:51 p. m.	7.08
[illegible]	19.48	[illegible]	8.07	2:56 p. m.	7.01	2:58 p. m.	8.07	2:52 p. m.	7.13
[illegible]	19.53	[illegible]	8.08	3:56 p. m.	7.03	[illegible]	8.10	[illegible]	7.15
[illegible]	19.58	[illegible]	8.12	4:55 p. m.	7.06	4:57 p. m.	8.13	4:51 p. m.	[illegible]
4:00 p. m.	19.61	[illegible]	8.14	5:56 p. m.	7.08	5:58 p. m.	8.14	5:52 p. m.	7.21
4:59 p. m.	19.58								
[illegible]	19.31								
SEPTEMBER 5									
6:24 a. m.	19.60	6:16 a. m.	8.29	6:19 a. m.	7.20	6:21 a. m.	8.24	6:13 a. m.	7.38
[illegible]	19.59	[illegible]	8.30	6:47 a. m.	7.22	6:49 a. m.	8.25	6:43 a. m.	7.39
[illegible]	[illegible]	7:33 a. m.	7.75	[illegible]	6.73	7:37 a. m.	7.47	7:32 a. m.	[illegible]
[illegible]	8.56	8:03 a. m.	[illegible]	[illegible]	6.56	8:07 a. m.	7.23	8:01 a. m.	6.90
7:01 a. m.	7.24								
7:02 a. m.	7.03								
[illegible]	6.99								
7:04 a. m.	6.97								
[illegible]	6.94								
7:07 a. m.	6.90								
7:08 a. m.	6.87								
7:09 a. m.	6.86								
7:10 a. m.	6.84								
7:15 a. m.	6.78								
7:20 a. m.	6.71								
[illegible]	6.67								
7:30 a. m.	6.64								
[illegible]	6.60								
[illegible]	6.57								
[illegible]	6.54								
7:50 a. m.	6.51								
7:55 a. m.	6.48								
[illegible]	6.46								
[illegible]	6.44								
[illegible]	6.42								
8:15 a. m.	6.40								
[illegible]	6.38								
[illegible]	6.36								

1 Pump started.

2 Pump stopped.

[illegible] (Continued)

[illegible]		[illegible]		[illegible]		[illegible]		[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Time	[illegible] water (feet)	[illegible]	Depth to [illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.76
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.53
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	11:08 a. m.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11:41 a. m.	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12:10 p. m.	[illegible]	[illegible]	6.09
[illegible]	[illegible]	1:07 p. m.	[illegible]	1:09 p. m.	5.77	1:11 p. m.	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.73
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.61
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.58
9:55 a. m.	[illegible]								
1:15 p. m.	[illegible]								
1:30 p. m.	[illegible]								
2:30 p. m.	[illegible]								
2:45 p. m.	[illegible]								
[illegible]	5.62								
[illegible]	5.61								
[illegible]	5.58								
7:01 p. m.	[illegible]								
[illegible]	5.47								
[illegible]									
[illegible]	[illegible]			[illegible]	5.19	6:06 a. m.	5.18	[illegible]	[illegible]
[illegible]	[illegible]			[illegible]	5.20	7:11 a. m.	5.17	[illegible]	[illegible]
[illegible]	[illegible]			8:19 a. m.	5.19	8:11 a. m.	[illegible]	[illegible]	5.08

[illegible] of a foot. The pump was operated continuously [illegible] with the exception [illegible] between [illegible] a. m. on September [illegible] gallons a minute. [illegible] feet south of the well, were used to measure the rate of discharge from the pump. The [illegible] tion ditch to a potato field about half a mile south of the well. Measurements of the depth to water in all the wells were made during the daylight hours of the test, but none were made at night. After the completion of the pumping period, measurements were continued [illegible] water table could be determined. The measurements of depth to water made during the test are given in table 7.

Thiem's equation requires the draw-down at 2 points on the cone of depression for computing the coefficient of permeability. During the early part of a pumping period, before the cone of depression has developed extensively, the difference in draw-down in two observation wells at different distances from the pumped well will change because considerable water is still being removed from storage in the vicinity of the wells. As the pumping progresses, the cone of depression develops and approaches an equilibrium condition with the [illegible] the difference in draw-down approaches a

constant value. Thus, the closest value to the actual coefficient of permeability will be obtained by using draw-downs at the end of the pumping period. As none of the observation wells penetrated to the bottom of the aquifer, the vertical thickness of the saturated part of the water-bearing bed is known only from reports. This is taken as 45.5 feet.

The coefficients of permeability computed from the test ranged rather widely. A study of the test data gives some clues with which to explain this difference in the coefficients. The inconsistent draw-down in the observation wells may be due largely to the heterogeneous character of the water-bearing material, which may not have allowed changes in water pressure to be freely transmitted to the observation wells. Lack of data as to the average thickness of the saturated part of the water-bearing bed at the observation wells also affects the computations of permeability.

Another factor influencing the computations of permeability was the stopping of the pump for about 45 minutes on the morning of September 4. Wenzel [17] found in his second pumping test in Nebraska, that the shape of the cone of depression altered considerably once the pump was stopped. Also, it was found that when pumping was started again, the cone of depression did not regain the form it possessed before pumping stopped, at least during the period of observations.

After a critical study of the data it was concluded that the coefficient of permeability of the material was between 3,000 and 5,000. The coefficient of permeability determined in the laboratory for a sample taken just above the water table at a depth of 4.0 to 4.5 feet at the observation well 12K14A1 (table 4) is 600. As the sand and gravel become coarser with depth, this sample is not representative of the saturated part of the aquifer.

Upon completion of the period of pumping, measurements of depth to water were made at intervals for a period of about 25 hours in the four observation wells and in the pumped well in order to observe the rate of recovery and to apply thereto the equation developed by Theis. (See table 7.) This equation is written in the following form:

$$T = \frac{264F}{V'} \log_{10} \frac{t}{t'}$$

in which T = the coefficient of transmissibility.

F = rate of pumping in gallons a minute.

V' = residual draw-down—that is, the distance the water level stands below its equilibrium position, in feet.

t = time since pumping started.

t' = time since pumping stopped.

It will be noted from figure 53, that all of the measurements from about 10:30 a. m., on September 5, 3.5 hours after pumping stopped, to the last measurement, 25 hours after pumping stopped, give consistent results, but the measurements prior to 10:30 a. m. do not. Using only the results obtained after 10:30, the coefficient of transmissibility is 216,000; and with a thickness of water-bearing material of 45.5 feet the coefficient of permeability is computed to be about 4,800.

Specific yield of the materials.—The specific yield of a rock or soil has been defined as "the ratio of (1) the volume of water which, after being saturated, it will yield by gravity, to (2) its own volume. This ratio is stated as a percentage and may be expressed by the formula $Y = 100 \left(\frac{y}{V}\right)$, in which Y is the specific yield, y is the volume of water in the rock or soil, and V is the volume of the rock or soil." [18] The specific yield of a rock or soil is difficult to determine experimentally, requiring a large expenditure of time and equipment. No attempt was made during the present investigation to determine directly the specific yield of the water-bearing material in the valley. It is possible, however, to arrive at a value for the specific yield indirectly, based on its relation to other physical properties of water-bearing material.

The specific yield is equal to the porosity minus the specific retention. If, as is sometimes done, the moisture equivalent is used roughly for specific retention, the difference between porosity and moisture equivalent is an approximate measure of the specific yield. Both porosity and moisture equivalent may be determined in the laboratory with relative ease. Recently Piper [19] has shown by experiments covering periods of drainage up to 400 days, the relation between moisture equivalent and specific retention. In table 4, the specific retention is shown as computed from the curve developed by Piper, and the specific yield is shown as the difference between the porosity and the specific retention. The specific yield of 19 samples thus determined ranged from 7.8 to 36.7 percent and averaged 28.9 percent.

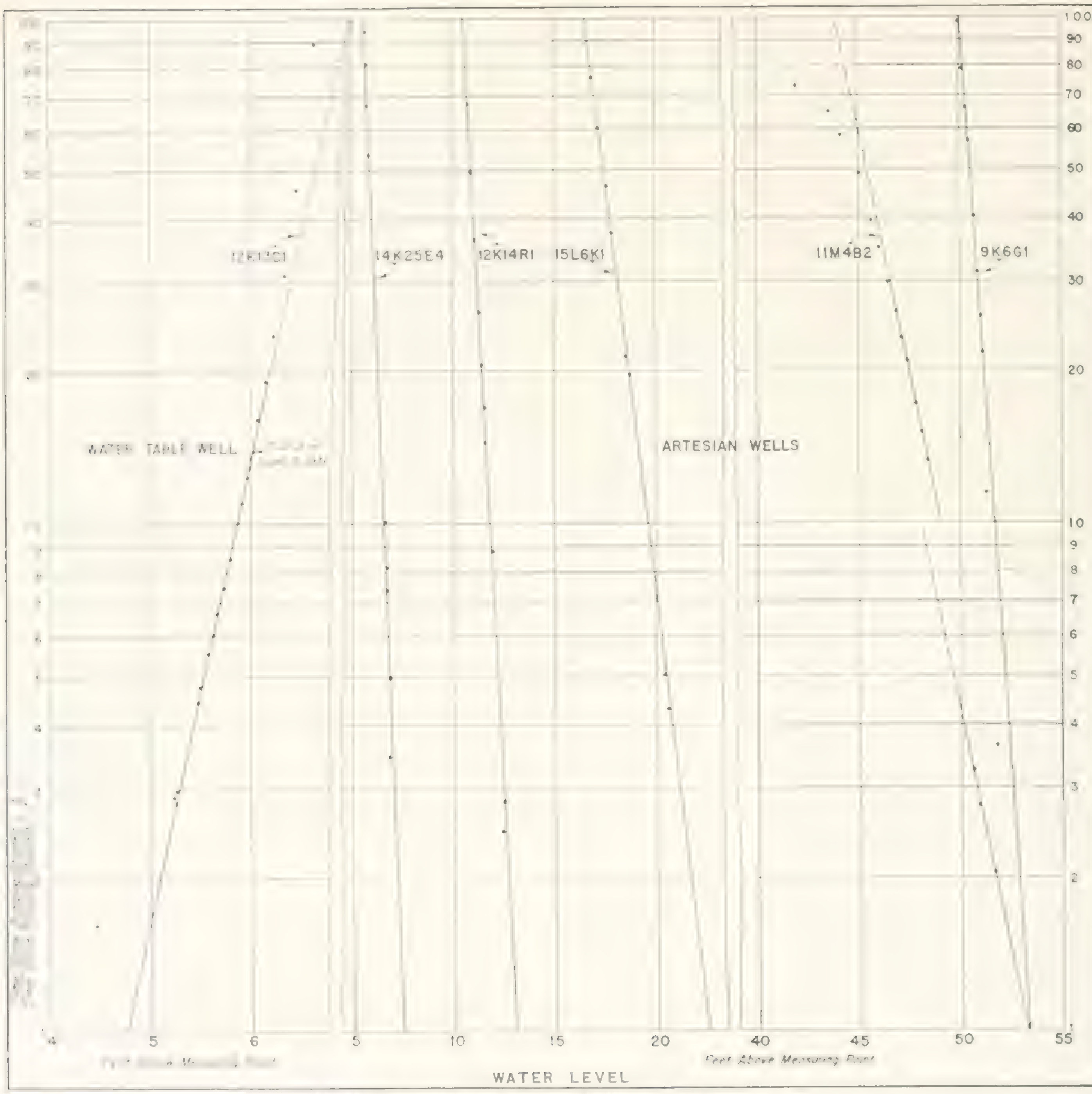
Yield of water to wells.—As has already been pointed out, the materials of the shallow fill of San Luis Valley range widely from clays to coarse gravel. As a result, the yield of wells that penetrate the sediments also ranges widely. Coarse sand and gravel yield water readily, whereas fine sands, silt, and clay yield water slowly. With the exception of the observation wells, bored by different agencies to observe water levels,

[17] Wenzel, L. K., The Thiem method for determining permeability of water-bearing materials: U. S. Geol. Survey Water-Supply Paper 679–A, pp. 32–34, 1935.

[18] Meinzer, O. E., Outline of ground-water hydrology: U. S. Geol. Survey Water-Supply Paper 494, p. 28, 1923.

[19] Piper, A. M., Notes on the relation between the moisture equivalent and the specific yield of water-bearing materials: Am. Geophys. Union Trans., 1933, pp. 481–487.

Piper, A. M., Thomas, H. E., and Robinson, T. W., Ground-water hydrology of the Mokelumne area, Calif.: U. S. Geol. Survey typewritten report, Oct. 30, 1935.



nearly all the wells in the shallow valley fill have been sunk to provide water for irrigation. As artesian water can be obtained at moderate depths over most of the valley floor, virtually no shallow wells have been put down for domestic or stock use. The water-yielding capacity of the sediments is best shown by studying the locations and yields of wells that have been sunk in order to pump water for irrigation.

Irrigation wells have been sunk in nearly every part of the valley, but in only a few localities have they been successful. These localities are all on the west side of the valley, on or adjacent to the alluvial fans. The locations of irrigation wells are shown on the map of the valley, plate 11. (Map vol.) The greatest concentration of irrigation wells is on the Rio Grande alluvial fan, another group is located east of the Monte Vista canal in the Carmel-Bowen drainage district, and a few are scattered on either side of the Rio Grande in the vicinity of Parma. With the exception of a few failures due to methods of construction, all the irriga-

tion wells in these areas are successful. The average yield of the wells is about 850 gallons a minute (p. 248), although some wells were reported to yield as high as 1,600 gallons a minute (table 12). Some of the irrigation plants pump only a few hundred gallons a minute, but in these the yield is limited by the capacity of the pumping plant and not by the capacity of the well. The wells with the highest yields are located on the Rio Grande alluvial fan. It is apparent that in these localities the sediments yield water to wells readily. Doubtless with further development the areas of pumped wells will be expanded to the north and south, but not much to the east.

In the central and eastern parts of the valley, practically all attempts to pump for irrigation have been failures, mostly because of the inability of the sediments to yield water readily.

About 1913, tests were made in sec. 1, T. 44 N., R. 9 E., about 6 miles north of Moffat, to determine the feasibility of irrigating by pumping from wells. A report by F. H. Whiting,[20] consulting engineer, describes the tests as follows:

> The first well sunk was carried to a depth of 60 feet, but proved to be in material yielding little or no water. The adjacent four wells put in after this one proved to yield three-fourths of a second-foot per well. * * *
>
> Four additional wells were drilled in sec. 26, T. 44 N., R. 8 E. These wells under ordinary pumping have yielded 1 second-foot each.

This last group of wells was located about 8 miles southwest of the first group, where the sediments are coarser.

Well No. 11L14E1, belonging to John Achaz, located about 5 miles southeast of Hooper, was dug for an irrigation well. It had to be abandoned for this purpose, as it did not yield sufficient water. An inspection of the spoil pile showed that the water-bearing material was composed mainly of fine sand with a few scattered pebbles.

An abandoned irrigation well owned by E. T. Dow is located in the NW¼ sec. 14, T. 38 N., R. 12 E., about 13 miles northeast of Alamosa. This well, originally dug 10 feet in diameter and 15 feet deep, was, according to the owner, exhausted in 28 minutes when pumped at the rate of 600 gallons a minute. Examination of the water-bearing material was difficult, as the well had not been in use for several years, though indications were that it was rather fine and would not yield water readily.

An attempt was made about 1934 by the city of Alamosa to supplement its water supply from the shallow ground water. A well of large diameter was sunk and tested from time to time at different depths, but it did not yield sufficient water and was finally abandoned. The driller reported the material penetrated as alternating strata of clay and fine sand.

[20] Whiting, F. H., Preliminary report upon the Moffat Irrigation District (manuscript copy), p. 32, Saguache, Colo., 1913.

From the foregoing discussion, it is apparent that the sediments in the central and eastern parts of the valley yield water to wells with difficulty, but on the west side the coarse gravel and sands yield water readily.

The Water Table

Location and description of observation wells.—In order to determine the nature and fluctuation of the water table, the depth to the water level was measured periodically in observation wells distributed over the valley floor. The observation wells are divided into two groups—one group located north and the other group south of the Rio Grande. In the group north of the river, located in the closed basin area and on the Rio Grande alluvial fan, there are 245 wells. In the south group, located in the Bowen, Carmel, Morgan, and Waverly drainage districts, and on the alluvial fan of Gato and Alamosa Creeks, there are 74 wells. The locations of the observation wells are shown on plate 5.

Except on the two alluvial fans, there are very few wells in the shallow valley fill in the entire valley. Therefore, it was necessary to bore most of the observation wells. Considerable difficulty was experienced in boring the wells, especially on the west side of the valley, because of the coarse sand and gravel that were encountered. This material slumped and caved so badly that many holes had to be abandoned. In these places 1-inch pipes, pointed on the end and perforated for a foot above the points, were driven into the ground far enough so that the points were well below the water table. In the trough of the valley north of the river, some trouble was experienced with fine sand filling up the wells from the bottom. None of the wells bored were over 12 feet in depth and nearly all were 10 feet or less in depth, 2 inches in diameter, and cased with galvanized iron casing to the bottom.

In the period 1931 to 1933, engineers from the States of Colorado and New Mexico bored about 250 wells in the closed basin area in order to observe the groundwater level. Measurements of depth of water were made by the Colorado engineers in their wells at intervals through the spring, summer, and fall of 1931 and 1932. Measurements were continued by the New Mexico engineers in their wells at frequent intervals until the fall of 1935. In order to continue the record of water-level measurements all except 1 of the 126 New Mexico wells were recovered and measured during the present investigation. However, only 24 of the Colorado wells were measured. A few of them could not be found, a large number were either destroyed or in such bad condition that they were useless as observation wells, and many were situated so near to New Mexico wells that measurements on them would be a duplication of work.

Levels had been run by engineers from both Colorado and New Mexico to the wells established by them, and these level data were made available for use in the present investigation. Levels were also run to about 65 of the wells that were put down in 1936, based on the 1929 general adjustment of the first-order level net. The levels run by the Colorado and New Mexico engineers were based on the earlier adjustment of the first-order level net. In order that all of the altitudes, determined by the three sets of level lines, would be comparable, the altitudes determined by the Colorado and New Mexico engineers were reduced and adjusted to the 1929 general adjustment.

Different systems of numbering were used by the Colorado and New Mexico engineers to designate their wells. In order to incorporate the wells in one numbering system for the present report, a rectangular coordinate system for numbering all the wells was used, based on the General Land Office subdivisions. The townships were assigned numbers and the ranges letters. Thus the first two characters of the well number designate the township and range in which the well is located. The next one or two numbers designate the section in which the well is located. The section was further divided into sixteen 40-acre tracts, each of which was assigned a letter as shown by the accompanying diagram. The letters I and O were omitted so that they would not be confused with 1 and zero. The first

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

well recorded in a 40-acre tract is numbered 1, the second 2, and so forth. The townships were numbered from north to south and the ranges from west to east. The numbers assigned to the township and the letters assigned to ranges are shown on plate 5. Thus, for example, a well located in the NE¼NE¼ sec. 16, T. 39 N., R. 9 E., would be numbered 12L16A1. A second well in the same 40-acre tract would be numbered 12L16A2. Such a system of numbering serves a double purpose, that of designating a well and also locating it, once the key number and letter are known.

Form of the water table.—The form of the water table in the closed basin area in October 1936 is shown by ground-water contours on the map (pl. 5), wherever there are sufficient data. Because of the steep slope of the water table on the Rio Grande alluvial fan and the very gentle slope in the trough of the valley, three contour intervals are used to show the form of the water table—a 5-foot interval below 7,520 feet, a 10-foot interval between 7,520 and 7,540 feet, and a 20-foot interval above 7,540 feet. No ground-water contours are shown south of the Rio Grande, as the altitude of the measuring points was not determined for a sufficient number of wells.

The water table closely resembles in form the general land surface. A comparison of the water-table map with Siebenthal's [21] topographic map of the valley shows a striking similarity. In general, the water table slopes from the west, north, and east sides toward the trough of the valley. The trough of the water table follows closely the trough of the valley floor, which extends from north to south along the old channel of San Luis Creek. Like the land surface, the water table is characterized by a relatively gentle slope from the west side to the trough of the valley, and a relatively sharp slope from the east. An example of this is best seen by examining the profile along the township line common to Tps. 39 and 40 N. In a distance of 24 miles from well 12J1H1, in the northeast corner of range 8, to well 11Q31N1, in the southwest corner of range 12, the water table descends 157.3 feet, or an average of about 6.5 feet to the mile; whereas, in a distance of 2 miles between well 11Q33N1 and well 11Q31N1, the water table descends 24.9 feet, or an average of about 12.4 feet to the mile. The slope of the water table on the west side of the valley, however, is not uniform, but becomes progressively flatter toward the east. As an example, in the profile just mentioned, the average slope for a distance of 12 miles east of well 12J1H1 is 9.1 feet to the mile, but for the remaining 12 miles it is only 4.0 feet to the mile.

Beginning about 9 miles south of Saguache, in the vicinity of Russel Lakes, the contours indicate a broad shallow depression of the water table, extending east toward the main depression of the trough. The lowest part of the water table is a closed depression in the vicinity of well 13N1A1, about 6 miles south of San Luis Lake, which is indicated by the closed 7,510- and 7,515-foot contours. South of this depression the trough of the water table continues toward the Rio Grande but is much constricted.

Direction of movement of the ground water as indicated by the water table.—The movement of ground water is in the direction of the maximum hydraulic gradient, at right angles to the contours of the water table. The shape of the contours indicates that on the Rio Grande alluvial fan, which is the principal area of recharge on the west side of the valley, the ground water is moving radially outward toward the northeast, east, and southeast. The contours show that the water in the shallow valley fill is moving from the foothills toward the trough of the valley, except along the south side of the Rio

[21] [illegible]

Grande fan north of the river between Monte Vista and Alamosa, where they indicate that the ground water is deflected somewhat toward the Rio Grande. With this one exception, the water table contours indicate that for October 1936 none of the water in the shallow valley fill of the closed basin area was moving out of the area. In the trough of the valley the ground water is moving from north to south toward the closed depression south of San Luis Lake. However, between San Luis Lake and the closed depression the water table is quite flat, indicating slow movement. Here large amounts of the ground water inflow are dissipated by evaporation and transpiration. The closed depression is probably due to heavy discharge by transpiration and evaporation.

Depth to the water table.—Over most of the valley floor the depth to water rarely exceeds 10 feet. Only on the steep alluvial slopes and alluvial fans is the depth to water great, in places amounting to 100 feet, or more. The depth to water varies from place to place over the valley, and to some extent from month to month in the same place, as is shown by depth to water measurements. As shown on the map (pl. 5), the depth to water in the closed basin area is less than 5 feet over approximately 70 percent of the area and from 5 to 8 feet over approximately 20 percent of the area. In only two localities in the closed basin area does the depth to water exceed 8 feet. These lie just to the west of the valley trough, one a few miles south of Moffat, and the other about 8 miles southeast of Mosca.

Over most of the area south of the Rio Grande, in the Carmel-Bowen drainage district and the general area east to the river, the depth to water is less than 5 feet. To the west, where the topography of the alluvial fan of Gato and Alamosa Creeks begins to develop, the depth to water increases, and farther west and higher up on the fan the depth to water is greater than 100 feet.

Influence of drains on the water table.—Since about 1910 numerous drainage systems have been constructed in the San Luis Valley, principally along the west side. The development of the drainage systems was a piecemeal process, as a rule each being constructed independently. They consist of both buried and open drains, the buried drains usually discharging into the open drains. They have been quite effective in lowering the water level wherever the water level was excessively high and the land had become "water logged." At present there is a network of drains over most of the agricultural lands on the west side of the valley.

It is not believed that these drainage systems in the closed basin area have changed materially the general form of the water table. Their general effect has been to lower the water table a few feet and to maintain it at a more or less uniform depth over the drained area. There is not sufficient information available to show the local effects of individual drains. It is to be expected that adjacent to the drains the water table is relatively low and that the distance through which the water table is lowered depends upon the permeability of the water-bearing material.

Fluctuations of the water table.—Seasonal Fluctuations.—A condition of approximate equilibrium exists between the amount of water annually replenishing the ground-water supply and the amount annually discharged. This balance is maintained through the changing conditions by fluctuations of the groundwater level. When the amount of recharge exceeds the amount of discharge the water table rises, and conversely when the discharge exceeds the recharge the water table is lowered. In the San Luis Valley fluctuations of the water table follow closely the seasons, but the seasonal fluctuations vary from place to place.

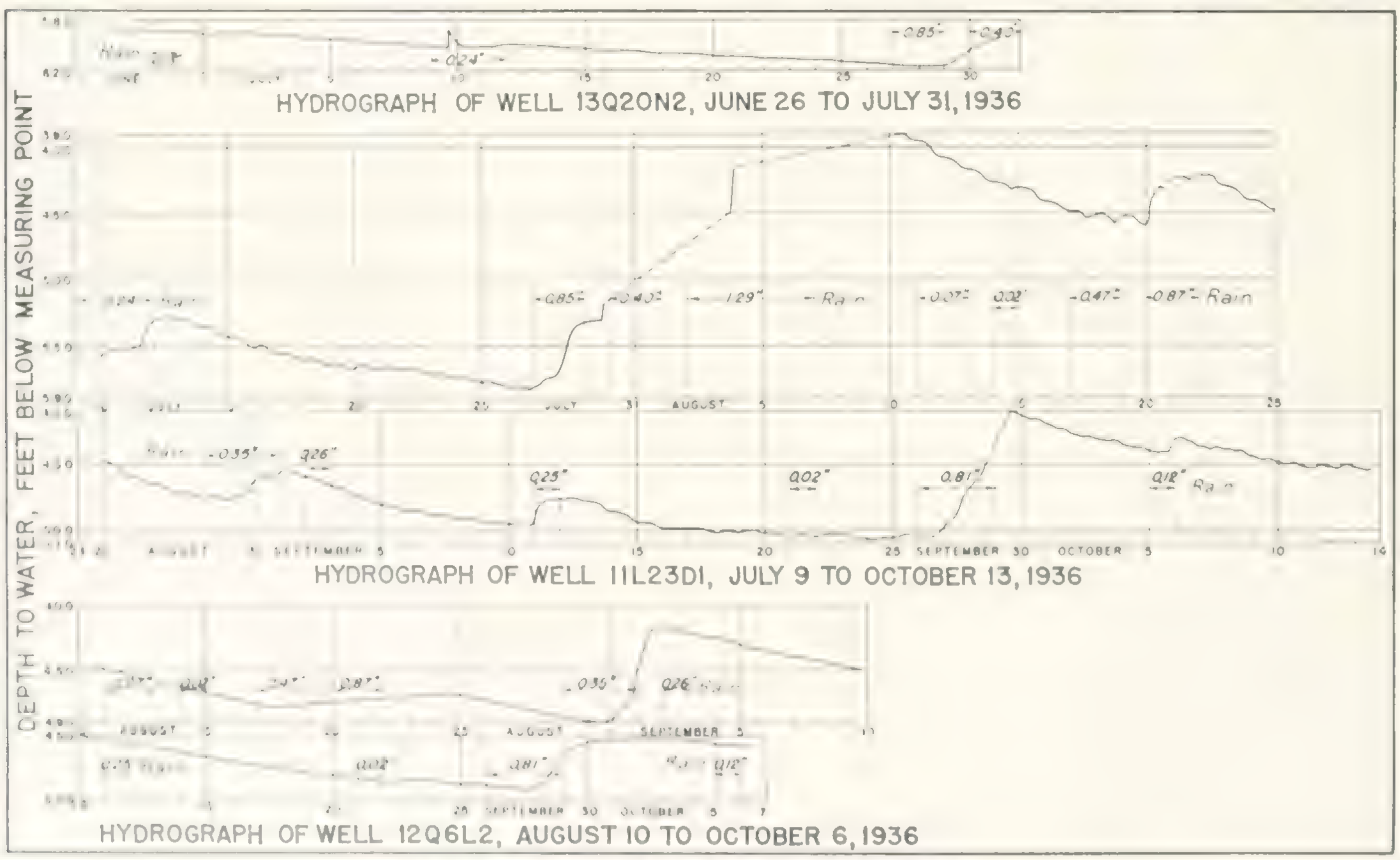
The common method of irrigation in the valley is by subirrigation—that is, by raising the water table and maintaining it or the overlying capillary fringe within the root zone of the plants during the growing season. The result of this practice is a very sharp and pronounced rise of the water table in the irrigated area with the beginning of the irrigation season, usually about the first of April. The two principal areas in which irrigation is practiced are on the Rio Grande alluvial fan and in the area south of Monte Vista that is served by the Monte Vista and the Empire canals. At the end of the irrigation season, the water level gradually declines until the next season. An example of this seasonal rise and decline on the Rio Grande alluvial fan is shown by the measurements of depth to water in well 12J10K1, owned by E. L. Neff. In this well the water level rose 10.5 feet between April 2 and June 8, 1936, then declined, so that on December 17 it stood 3.77 feet below its position on June 8. Because of a shortage of irrigation water early in July, the "sub" could not be maintained, and consequently the water level declined sharply. However, a supply of water became available in August that partly restored the water table to its June level.

In the northern, central, and eastern parts of the closed basin area the agricultural lands give way to meadow and brush lands. Irrigation water is usually applied to the meadowlands but not to the brushlands. The vegetation on both types of land is for the most part composed of plants that habitually feed on ground water. The brush cover is locally referred to as "chico", but it is made up chiefly of two dominant plant species, greasewood and rabbitbrush, with greasewood the more prominent. The meadow lands are largely covered with salt grass, which discharge large quantities of ground

water by transpiration, resulting in a decline of the water level until the end of the growing season. When the transpiration draught ceases or becomes light the water level starts to rise, and it generally continues to rise slowly through the winter. With the advent of warm weather, the ground thaws and allows the melted snow water and rainfall to percolate downward to the water table, resulting in a sharp rise of the water level. The water level then remains high until the transpiration draught is resumed. This condition is shown by the records of depth to water obtained prior to 1936 in the New Mexico wells located in the transpiration area. During the latter part of July and first part of August 1936, unusually heavy rains produced a pronounced rise of the ground water levels. Thus the effect of transpiration on the lowering of the water table is not so pronounced for the 1936 season as for some previous seasons, although the trend is indicated by the June and July measurements.

Diurnal Fluctuations.—In order to obtain a record of diurnal fluctuations of the water table, three wells in the closed basin area were equipped with automatic water-stage recorders. These wells, 11L23D1, 12Q6L2, and 13Q20N2, are in the general area where the conditions are favorable for the transpiration of large quantities of water. Well 13Q20N2 is located about 10 miles east and north of Alamosa, well 12Q6L2 about 1½ miles southeast of San Luis Lake, and well 11L23D1 about 6½ miles northwest of Mosca. These wells are 18 inches square and were dug especially to accomodate the recorders. The recorders were Stevens 8-day type L, which operate on a time scale of 1 inch to 10½ hours and a 1 to 1 or natural water-height scale. The records obtained on these wells are shown in figure 54.

All the wells were located in extensive areas of greasewood, rabbitbrush, and salt grass. In the vicinity of well 11L23D1, the growth was much thicker and more vigorous and luxuriant than at either of the other two wells, and the hydrograph of this well shows large diurnal fluctuations. No diurnal fluctuation was observed in well 13Q20N2 and only faint fluctuations in well 12Q6L2. It is not clear why the diurnal fluctuations were not more pronounced in these two wells, but the reason may lie in part in the difference in the density and growth of the vegetation and in part in difference in the texture of the soil. However, it will be noted that in all of the wells there was a net decline in the water level from day to day except during and immediately following periods of heavy rain. This decline is



the result of draft by transpiration and probably in small part by soil evaporation.

The hydrograph of well 11L23D1 shows that the water table goes down during the daytime when transpiration is rapid, and rises at night when transpiration is low. Usually the water starts downward about 10 a. m., reaching its low stage between 7 and 8 p. m. Between about 9 and 11 p. m., the water begins to rise perceptibly, and it continues to rise until about 9 the next morning. The maximum daily fluctuation observed during the period in which the recorder was in operation amounted to about 1 inch. During and immediately following periods of rain the diurnal fluctuations are replaced by rapid rise of the water table. For a short period after the period of rise, the water level remains practically stationary and then it declines rapidly. During the period of decline the diurnal fluctuations are superimposed on a rapidly declining water level, and hence the amount of the daily rise is reduced and that of the daily decline is increased.

Beginning about September 30 a different type of diurnal fluctuation is shown by the hydrograph of well 11L23D1. The water level began to rise about 11 a. m. and continued to rise until about 4 p. m., which is the opposite of the daytime decline caused by transpiration. Beginning on the afternoon of September 26, rain started falling, and the rain was followed by several inches of snow on September 27. After the storm the temperature dropped below the freezing point each night, thus definitely ending the growing season and the transpiration draft. The daytime rise of the water table was evidently due to water from the melting snow and ice percolating downward to the water table.

Fluctuations Caused by Rainfall Penetration.—Fluctuations of the water table due to rainfall penetration are indicated by the monthly measurements of depth to water and are shown definitely by the hydrographs of the three recorder wells, 11L23D1, 12Q6L2, and 13Q20N2. The measurements in nearly every well in the closed basin area show that the water level stood higher in August and September 1936 than in July 1936. The records of the United States Weather Bureau station at Garnett, Colo., located in about the center of the closed basin area, show that the precipitation was only 0.68 inch in June, but that it was 1.49 inches in July, 3.07 inches in August, and 1.34 inches in September. The heavy rains in July occurred after the monthly round of measurements had been made, and hence their effect on the water table was not apparent until the August round of measurements.

The response to rainfall was much faster and of greater magnitude at well 11L23D1 than at either of the other two recorder wells. This was no doubt due to the greater permeability of the material in the vicinity of this well. Here the material consisted of coarse sand and gravel from the surface down to the water table, whereas at wells 12Q6L2 and 13Q20N2 the logs show a mixture of fine sand and clay. The permeability of the material in the zone of fluctuation (table 4, p. 233) was 1,500 at well 11L23D1, 65 at well 12Q6L2, and only 1 at well 13Q20N2.

The water table responded much more to heavy rains than to light rains. For rains of 0.10 inch or less the response was very slight. The greatest response was recorded in well 11L23D1 for the period July 27 to August 6, when 2.54 inches was recorded at Garnett. The exact rise of the water table is not known, as the recording pencil was forced off the chart. However, measurement on August 10, 4 days after the rain stopped, indicated a rise in excess of 1.85 feet. A rise is also shown on the hydrograph of well 13Q20N2 up to the afternoon of July 30, when the recorder ceased to function. Measurements in this well on July 20 and August 13, before and after the rainstorm, show that the water level rose 1.84 feet. The rain and snow storm of September 26 to 28, in which the total precipitation amounted to 0.81 inch at Garnett, produced a rise in excess of 0.90 foot at well 11L23D1 (here again the pencil was forced off the chart) and a rise of 0.40 foot at well 12Q6L2. The stairstep effect, in the hydrograph of well 13Q20N2, is due to the mechanical operation of the recorder in overcoming the frictional resistance of the recording device. On the same hydrograph the sharp vertical rise, amounting to 0.15 foot on July 8, was due to rain water entering the well at the surface, and not, as might be supposed, to rainfall penetration.

It must be borne in mind that the rainfall at the recorder wells may have differed considerably from the rainfall recorded at the United States Weather Bureau station at Garnett, but a comparison of the rainfall at this station and the hydrographs of the recorder wells makes it evident that a causal relationship exists. The hydrographs and the records of other observation wells also indicate that the rise of the water table differed from place to place over the valley floor, these differences probably being due to differences both in the texture of the shallow valley fill and in the amount of rainfall.

Fluctuations Caused by Pumping.—Within the last 5 years many farmers in the agricultural area on the west side of the valley have drilled wells and equipped them with pumping plants. The wells are usually of large diameter and penetrate only the shallow or unconfined water (table of irrigation wells, pp. 250 and 251). These irrigation wells are used only when there is a shortage of irrigation water. Such a shortage occurred during the season of 1936, beginning early in July.

[illegible] table, especially on the Rio Grande alluvial fan and in the Carmel-Bowen drainage district, which are the two areas of heavy pumping draft. (See the hydrographs of wells 11J9D1, 11J26P1, and 11K6N1 (fig. 55), [illegible]) In these parts of the valley the water level began to decline sometime after the June round of water level measurements and did not begin to recover appreciably until [illegible]. The rise in October was due to the cessation of pumping and some late irrigation with surface water.

Source of the Ground Water

Streams.—All the streams that enter the San Luis Valley flow across the alluvial slopes bordering the valley floor. As already pointed out (pp. 229-232), the material forming the alluvial slopes is coarse in texture and therefore the water percolates through it readily and the streams have large seepage losses. It is common knowledge that the flow of the minor streams dwindles noticeably after they reach the alluvial slopes, particularly the streams flowing from the Sangre de Cristo Range, only a few of which flow beyond the base of the alluvial slopes. Several of the streams flowing from the mountains on the west side of the valley are larger and are able to withstand heavy losses in flowing across the alluvial slopes, but the losses from the minor west-side streams are readily noticeable wherever the water has not been diverted for irrigation.

Prior to the time of any irrigation development on the Rio Grande and the Conejos River, these streams were undoubtedly large contributors to the ground water. This was especially true during flood periods, when the water spread out to inundate the flood plain. With the advent of irrigation development and consequent diversions, the flow in the river channels soon after emerging from their rock canyons was greatly reduced. At the present time nearly the entire flow of the Rio Grande is diverted in the upper part of its alluvial fan for irrigation. Thus with the changed regimen of the streams, the opportunity for ground-water recharge by stream losses was reduced.

The following table from a report by Carpenter[22] shows the seepage losses for sections of the Rio Grande between the Del Norte and Monte Vista gaging stations [illegible]

[illegible]

Vista

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	−57.43	−4.26	−79.07	[illegible]	−56.20
[illegible]	[illegible]	+54.32	+6.61	[illegible]	+2.46	−13.29	+19.11	[illegible]	+1.17
Monte Vista	18	−52.71	[illegible]	[illegible]	[illegible]	−17.55	[illegible]	[illegible]	[illegible]

Presumably this table of seepage loss or gain was compiled from special seepage measurements for short periods and is not the average for any 1 year or month. Results of the stream gaging in 1936 at the Del Norte and Monte Vista gaging stations (tables 10 and 11) do not show as great losses as those shown in the table for several years earlier. The highest loss in 1936 occurred during March and April, and amounted to 2,345 acre-feet, or an average of about 19.2 cubic feet per second. The stream losses shown by the above table, except in August 1900, occurred in the 8-mile section of the stream below the Del Norte gaging station, which is about at the apex of the Rio Grande alluvial fan. Thus it is apparent that nearly all of the stream loss takes place on the upper part of the fan. No measurements of discharge from this 8-mile section of the river are available for 1936, but as there has been little if any increase in the quantity of water diverted from it for irrigation since 1903, it is safe to assume that it still has appreciable seepage losses.

Carpenter[22a] also shows a similar set of seepage determinations for the Conejos River. Between the San Juan Bridge (at Mogote) and the Conejos Bridge (at Conejos), a distance of about 4 miles, there was a loss of 22.12 cubic feet per second in August 1900, and 4.66 cubic feet per second in October 1900, but a gain of 7.92 cubic feet per second in July 1903. This section of the river is well up on the alluvial fan and corresponds to the section between the Del Norte gaging station and Off's on the Rio Grande. No stream measurements are available from which to compute seepage losses in this section of the stream in 1936, but the conditions are favorable for contributions to the ground water by seepage losses.

Irrigation water.—During the irrigation season practically the entire flow of the Rio Grande is diverted for irrigation. In the calendar year 1936 these diversions amounted to 480,674 acre-feet. (See tables 10 and 11.) Most of this water is used on the Rio Grande alluvial fan and on the gravelly soil forming the base of the

[22] [illegible]

[22a] [illegible]

alluvial fans of Gato and Alamosa Creeks. Because of the method of irrigation and the type of soil the opportunity for ground-water recharge in these areas is great. As has been stated previously, the common method of irrigation is by raising the ground-water level and maintaining it about up to the root zone. As the soils are coarse and permeable, such a system of irrigation becomes a very effective method of ground-water recharge. It is essentially the same as water spreading for ground-water recharge. A similar condition of irrigation diversion and "subbing" exists for most of the streams entering the valley from the west side.

On the east side of the valley irrigation is not practiced extensively, chiefly because of a lack of water supply and because attempts to divert water on the alluvial slopes have failed on account of heavy ditch losses. Lining the ditches or fluming the water has apparently not been economically feasible. Any water from those streams that flow across the alluvial slopes is used to irrigate native hay meadows on the valley floor. In these meadows there is undoubtedly some ground-water recharge.

As a result of irrigation, there is without doubt much larger total recharge to the ground water in the valley now than before irrigation was practiced, evidence of which is furnished by the extensive system of drains that has been constructed to lower the water level and carry away excess ground water.

Artesian wells.—According to the artesian-well inventory (table 20), there are in the valley 6,074 wells, and these wells have an aggregate annual discharge of about 119,000 acre-feet. The flow of these wells is a potential source of water for recharge of the shallow ground-water supply. A small part of the total flow is used for domestic, industrial, and stock use; the remainder, being used for irrigation, is allowed to discharge directly on the land, where it is dissipated by evaporation and downward percolation. As the land surface in the area of artesian flow is relatively flat, most of the artesian water not used for irrigation disappears within a few hundred feet of the well. Of the artesian water used for irrigation a certain amount is lost by transpiration and evaporation. The cities of Monte Vista and Alamosa use artesian water and discharge some of it into the Rio Grande in the form of sewage, but the stream is diverted below both cities for irrigation. Thus, very little of the flow from the artesian wells passes out of the valley as stream flow, and the amount of artesian water available for ground-water recharge is essentially equal to the total flow of the wells less the artesian water lost by evaporation and transpiration.

Recharge of the shallow aquifer also takes place by underground leakage out of the artesian wells. In the early period of artesian development, many wells were cased only sufficiently to prevent the top of the hole from caving. The common practice was to use only one "stick" of casing, usually from 18 to 22 feet in length, and in some wells no casing was used. The casing was not long enough to be seated even on the first confining bed, thus allowing part of the water to come up on the outside of the casing and to enter the shallow aquifer. Proof that water from these inadequately cased wells is entering the shallow aquifer is shown by the increase in flow after a well has been recased and the casing has been properly seated. Thus drillers report that after recasing, the flow of the well is likely to increase two or three times.

Rainfall penetration.—It has already been shown (p. 243) that the water table fluctuates in response to rainfall. The hydrographs from wells equipped with automatic water-stage recorders show a material rise of the water level following periods of moderate to heavy rain, thus indicating recharge of the ground-water supply by rainfall penetration. These hydrographs further indicate that the amount of rainfall penetration varies from place to place. Doubtless on the coarse material of the alluvial slopes and fans a large part of the rainfall percolates to the water table, whereas on the finer material in the central part of the valley the amount of rainfall reaching the water table is less. A rough measure of the quantity of rainfall reaching the water table in the central part of the closed basin area is afforded by the rise of the water table in wells 9M2C1, 10M2A1, 11M1D1, 11N3R1, 12N23N1, 13M14D1, and 13Q20N2, which are located outside the influence of recharge from irrigation. The rise of the water level in these wells in the period of heavy rains from July 20 to October 15, averaged 0.94 foot, or 11.3 inches. In this period the precipitation, as recorded at the United States Weather Bureau station at Garnett was 5.78 inches. As the capillary fringe reaches virtually to the surface over most of the valley floor, capillary water occupies part of the pore space, and so the effective porosity of the material above the water table and therefore its capacity to absorb additional water is reduced. For this reason the figures for specific yield which are shown in table 4 cannot be used to compute the quantity of rainfall penetration from a known rise of the water table.

Precipitation in the valley during the rainy season is very irregularly distributed. Individual showers of varying intensity sweep across the valley in an easterly direction, covering strips only a few miles in width, outside of which the ground is often perfectly dry. Thus, for June 1936 the rainfall at Garnett was only half that at Alamosa, 20 miles south, while for July 1936 the rainfall at Garnett was one and one-half times that at Alamosa. As the texture of the soil and the amount and intensity of the rainfall range widely throughout the

valley, it follows that the amount of rainfall penetration also ranges widely. The small depth to the water table below the land surface is favorable to recharge by rainfall penetration, and the data presented show that the recharge from this source is a substantial quantity.

Disposal of the Ground Water

Processes.—The ground water in the shallow valley fill is discharged by soil evaporation and plant transpiration, underflow, artificial drainage, and pumping from wells. There are no known springs on the valley floor that discharge shallow ground water, but the several lakes are essentially outcrops of the water table. At the foot of the alluvial slopes there are springs such as Little Spring and Big Spring, east of the Medano Ranch, which discharge water that was lost by the streams farther up the alluvial slopes.

Evaporation and transpiration.—Wherever the water table stands close to the land surface, the ground water moves upward through the soil by capillary rise to be disposed of by evaporation, and in general the closer it is the greater is the amount of ground water evaporated. In a somewhat similar manner water is discharged by the plants where the water table stands within reach of the root zone. In the San Luis Valley the conditions are favorable for the disposal of large quantities of ground water by both evaporation and transpiration.

As shown on plate 11, there are in the valley extensive uncultivated areas occupied by native vegetation, which is composed almost entirely of plants that habitually feed on ground water, such as greasewood, rabbitbrush, and saltgrass. In the cultivated areas the practice of maintaining the ground-water level up to the root zone of the plants allows these plants to feed on ground water, even though they may not be habitual users of ground water. The map (pl. 5) shows that in July 1936 the water table in about 70 percent of the closed basin area stood less than 5 feet below the land surface, and that in only about 10 percent of the area was it more than 8 feet below the surface. Thus in all except a small part of the area the water table is within reach of the roots of ground-water plants. Much of the decline of the water table in the summer of 1936 was due to transpiration. And specific evidence of the disposal of ground water by transpiration is furnished by the diurnal fluctuations of the water table, as recorded by the automatic water-stage recorders (p. 242).

The [illegible] disposal of ground water by evaporation from the soil undoubtedly varies from place to place over the valley floor, with the depth of the water table below the land surface and the height of the capillary fringe, which in turn is governed by the texture of the soil. Undoubtedly there are areas in the floor of the valley where there is little or no soil evaporation, because of unfavorable combinations of depth to water and soil texture. There are, however, extensive areas, both bare and with vegetal cover, where soil evaporation is known to occur. Here the alkali salts left behind by evaporation have collected as a crust on the surface of the soil or appear as efflorescences. These alkali deposits were observed in nearly all parts of the valley but especially in the central trough.

No experiments were conducted during the present investigation to determine the rate of ground-water discharge by evaporation and transpiration, but some data are available from experiments conducted in the valley during 1930, and additional data are available from the work of others in areas comparable to the San Luis Valley.

During the growing season of 1930, Tipton and Hart [23] conducted experiments on soil evaporation in the San Luis Valley, in four soil tanks, each 3 feet in diameter and 4 feet deep, and with the water level at different depths. The results obtained are shown in the following table:

TABLE 9.—*Evaporation,*[1] *May to October, inclusive, 1930*

[illegible]

	Tank no. 1	Tank no. 2	Tank no. 3	Tank no. 4
	Vegetal cover			
	[illegible]	[illegible]	[illegible] sod	Bare
[illegible]	0.33	0.80	1.[illegible]	0.02
[illegible]	[illegible]	1.75	1.57	2.[illegible]

[1] Believed to include transpiration losses for tanks 1, 2, and 3.

These experiments, however, are applicable only to areas of saltgrass where the depth to water is less than 2 feet, or to bare land with the water table at the surface.

The rates of evaporation and transpiration discharge determined by White [24] in the Escalante Valley, Utah, are believed to be more or less applicable to the San Luis Valley. The Escalante Valley, though lower in altitude, is comparable to the San Luis Valley in many respects, such as topographic situation, climate, rainfall, and vegetative cover. White's results were based on experiments covering three growing seasons. In estimating the ground-water discharge, he classified the lands according to vegetative cover and according to depth to water. Thus in the lowland areas occupied by saltgrass associated with greasewood, rabbitbrush,

[23] [illegible]

[24] [illegible]

and pickleweed, with saltgrass dominant, where the depth to water was from 0 to 3 feet in the spring and 3 to 5 feet in the fall, 1 acre-foot per acre was taken as the probable ground-water discharge by evaporation and transpiration. In the area where the chief ground-water plants were greasewood, rabbitbrush, and shadscale, with a light growth of saltgrass, and the depth to water was from 0 to 5 feet in the spring and from 3 to 8 feet in the fall, 5 acre-inches per acre was used as the probable ground-water discharge by evaporation and transpiration. On somewhat higher lands occupied by greasewood, rabbitbrush, and shadscale, where the depth to water was from 8 to 30 feet, 2 acre-inches per acre was used as the discharge by transpiration, with no loss by evaporation.

Lee [25] in Owens Valley, Calif., conducted tank experiments to determine the loss of shallow ground water by evaporation and transpiration, and from the results of these experiments he estimated the amount of ground water evaporated and transpired annually.

Thus, knowing the depth to water and the kind and amount of vegetation, it is possible to estimate the annual discharge of ground-water by evaporation and transpiration. Such an estimate (p. 249), based on White's figures was made for the trough of the valley in the closed basin area, but no attempt has been made to estimate the discharge for the entire valley.

Underflow.—The statement is made on page 241 that the ground-water contours indicate movement of water toward the Rio Grande, especially along its alluvial fan. Such movement is indicated by the stream-flow records at Del Norte and Alamosa. Tables 10 and 11 show the seepage gain of the river by months for the calendar year 1936, between the Del Norte and Monte Vista gaging stations and the Monte Vista and Alamosa gaging stations.

These tables show that in all months in 1936 except January and November there was a net seepage gain in the river between Del Norte and Alamosa. This seepage gain amounted to a continuous flow for the year of about 72 second-feet. The two stretches of the river between the gaging stations are about equal in length, yet the seepage gain in the lower stretch is about twice that of the upper stretch. This is to be expected, as the seepage water, which is no doubt largely water diverted and used for irrigation, must move laterally a considerable distance from its point of application before it enters the river as underflow. That the seepage gain is largely irrigation water is shown by the facts that the largest gains occurred during the irrigation period, from April to October, and that in general during the late fall and early winter the seepage gain was small or there was a seepage loss from the stream. There are no data available to show from which side of the river the underflow is the greatest, but it probably comes largely from the north side. South of the river, a part of the underflow is probably intercepted by Rock Creek, which parallels the Rio Grande from Monte Vista to Alamosa.

It seems probable that prior to any irrigation development, the Rio Grande may have been a losing stream part of the time and a gaining stream part of the time—losing while in flood, when the water spread over its flood plain, and gaining after the flood water had receded. Under its present regimen, however, no floods of any consequence pass across the valley floor,

[25] Lee, C. H., An intensive study of the water resources of a part of Owens Valley, Calif.: U. S. Geol. Survey Water-Supply Paper 264, 1912.

TABLE 10.—*Monthly summation of inflow and diversions on the Rio Grande between the Del Norte and Monte Vista gaging stations to show seepage gain or loss*

[All quantities in acre-feet]

1936	January	February	March	April	May	June	July	August	September	October	November	December	Total
Rio Grande at Del Norte	9,320	9,970	13,880	67,330	141,200	89,150	39,550	37,570	27,100	15,130	12,930	9,710	[illegible]
Inflow (visible)	700	700	1,500	2,500	3,000	1,400	550	1,200	600	700	700	700	14,250
Total flow	10,020	10,670	15,380	69,830	144,200	90,550	40,100	38,770	27,700	15,830	13,630	10,410	[illegible]
Diversions	0	665	9,195	51,440	104,975	71,340	34,520	38,230	28,060	15,945	1,545	0	355,915
Difference	10,020	10,005	6,185	18,390	39,225	19,210	5,580	540	−360	−115	12,085	10,410	131,175
Rio Grande at Monte Vista	9,290	11,120	4,970	17,260	42,270	21,000	6,490	5,350	3,920	3,430	11,740	11,520	[illegible]
Seepage gain (+) or loss (−)	−730	+1,115	−1,215	−1,130	+3,045	+1,790	+910	+4,810	+4,280	+3,545	−345	+1,110	+17,185

TABLE 11.—*Monthly summation of inflow and diversions on the Rio Grande between the Monte Vista and Alamosa gaging stations to show seepage gain or loss*

[All quantities in acre-feet]

1936	January	February	March	April	May	June	July	August	September	October	November	December	Total
Rio Grande at Monte Vista	9,290	11,120	4,970	17,260	42,270	21,000	6,490	5,350	3,920	3,430	11,740	11,520	148,360
Inflow (visible)	200	400	900	900	900	900	900	900	900	900	[illegible]	900	9,600
Total flow	9,490	11,520	5,870	18,160	43,170	21,900	7,390	6,250	4,820	4,330	12,640	12,420	157,960
Diversions	0	0	4,585	20,240	44,030	25,945	7,830	8,220	6,685	5,115	2,105	0	[illegible]
Difference	9,490	11,520	1,285	−2,080	−860	[illegible]	−440	−1,970	−1,865	−785	10,535	12,420	33,205
Rio Grande at Alamosa	9,380	11,680	4,880	2,860	5,000	2,870	2,630	3,260	1,470	1,660	10,860	12,160	68,710
Seepage gain (+) or loss (−)	−110	+160	+3,595	+4,940	+5,860	+6,915	+3,070	+5,230	+3,335	+2,445	+325	−260	+35,505

[1] Partly estimated.

of the water is diverted for irrigation. Siebenthal[1] mentions a seepage loss of 75 second-feet between Del Norte and Monte Vista, indicating that in the early days of irrigation development, the stream on the upper part of its alluvial fan may have been a losing stream. However, no such loss is indicated by the stream measurements of 1936. Even for March, the month of greatest loss between Del Norte and Monte Vista, the amount is only 1,215 acre-feet, or an average flow of about 19.6 second-feet.

Artificial drainage.—A considerable quantity of shallow ground water is disposed of by means of the network of drains in the valley, but no systematic measurements have ever been made of this discharge. A part of the drain water is reused for irrigation and the rest is usually discharged into some stream. Practically the entire visible inflow between Monte Vista and Alamosa is drain water. As shown by table 12, this amounted to about 9,600 acre-feet during 1936. The amount undoubtedly varies from year to year, depending upon the available irrigation water. It was noted that during the shortage of irrigation water in July and August 1936, some of the drains were barely flowing, while in others the flow was greatly reduced.

Pumping.—During periods when there is a deficiency in irrigation water, the stand-by irrigation pumps are put in operation. As stated previously (pp. 243 and 244) this practice has only become general within the last 5 years. The location of the pumping plants is shown on plate 11, and a brief description of each is given in table 12.

The quantity of water pumped is variable, depending upon the available supply of surface water. On account of the permeable nature of the soils, a large part of the water pumped no doubt percolates back to the water table, but at points farther down the slopes. Thus only a part of the water pumped is permanently removed from the shallow aquifer.

A reconnaissance during the summer of 1936 showed that there were 176 pumping plants in the valley. Many of these had been installed since 1931, and some were just being installed. No measurements of discharge were made, but a reported discharge by the owner or operator was obtained for 99 of the plants. These reported discharges ranged from 100 to 1,600 gallons a minute, with an average of 850 gallons a minute. On this basis the total capacity of all the plants, pumping continuously, would be about 660 acre-feet per day, or about 330 second-feet.

Most of the pumping plants were operated with farm tractors or old automobile engines, a few were electrically operated, and some were operated by stationary gasoline engines. As the plants are used only for standby purposes, the power units were for the most part only temporary and were moved away as soon as the pumping period was over.

General Conclusions

Because of the limitation of time, the present investigation was necessarily qualitative in nature rather than quantitative, and the data were collected with the view of studying the nature and behavior of the water in the shallow valley fill rather than the quantity. Thus, although the processes by which water is added to and discharged from the shallow ground water have been discussed, no estimates have been made of the quantities involved. Quantitative studies based on work during only one season are not as a rule applicable over a period of years. It is possible, however, from the available data to make some statements as to the magnitude of the quantities involved.

As shown on pages 244 and 245, the principal area of recharge in the closed basin area is on the Rio Grande alluvial fan, as the result of irrigation. Using the coefficient of transmissibility of 216,000, determined from the pumping test on well 12K13D1 (see p. 237), and the hydraulic gradient of the water table as shown by the map (pl. 5), a rough estimate can be made of the quantity of water moving radially outward from the fan. In general the toe of the fan corresponds to the position of the 7,600-foot contour of the water table, above which most of the irrigation and hence recharge takes place. The average hydraulic gradient along the 7,600-foot contour is about 8 feet to the mile. Thus the available data indicate that for each mile along this contour, water is moving out of the fan at the rate of about 1,900 acre-feet a year. The distance along the contour from the Gunbarrel Road (line common to Rs. 7 and 8 E.) to the Rio Grande is about 24 miles. On this basis, the movement of water out of the fan would amount to about 45,000 acre-feet annually.

This water moving out of the fan into the lower part of the valley is disposed of by several processes. A large part undoubtedly is discharged by evaporation and transpiration in adjacent areas where the water table stands close to the land surface. Of the remaining part, some is intercepted by drainage ditches to be reused for irrigation or discharged into the Rio Grande, some percolates into the Rio Grande as underflow, and some percolates farther eastward into the trough of the valley and is there discharged by evaporation and transpiration. This lateral percolation from the west into the trough of the valley is believed to be relatively small.

Nine samples of the water-bearing material taken at or immediately above the water table, from wells located

[1] [illegible]

along and just west of the valley trough (wells 9M2C1, 10M2A1, 11M1D1, 11M36R1, 11N3R1, 12N23N1, 12Q6L2, 13M14D1, and 13Q20N2), were tested in the hydrologic laboratory of the Geological Survey at Washington, D. C., for permeability. One sample was nearly impermeable and one had a coefficient of permeability of 900. The coefficients of permeability at the other wells ranged from 20 to 180 (table 4, p. 233). The average for the nine samples was approximately 150. The thickness of the shallow valley fill along the trough of the valley from the vicinity of Moffat south to Washington Springs, based on all available well logs and information received from local well drillers, ranges from 24 feet to 185 feet, and averages about 90 feet. On this basis the average coefficient of transmissibility in the trough of the valley was computed to be about 13,500.

An inspection of the water-table map (pl. 5) shows that the 7,540-foot contour of the water table encloses practically all of the valley trough from 2½ miles south of Moffat south to Washington Springs. The average hydraulic gradient at this contour is about 7 feet to the mile. Roughly the gradient on the east side of the trough is about twice that on the west wide, indicating that, transmissibility being equal, twice as much water percolates into the trough from the east than from the west. However, it seems probable that the transmissibility is somewhat greater on the east side. None of the samples tested for permeability were taken east of the valley trough. Here the water-bearing material is derived from the nearby steep slope of the Sangre de Cristo Mountains, and would tend to be coarser and hence have greater permeability than the material transported across the valley from the west. Using the data for transmissibility and the hydraulic gradient, the lateral percolation per mile past the 7,540-foot contour was computed to be about 105 acre-feet a year. The length of the 7,540-foot contour in its loop around the trough of the valley, from the vicinity of Alamosa north nearly to Moffat and then south to the vicinity of Washington Springs, is about 75 miles. On this basis, the lateral percolation into the trough of the valley was computed to be about 8,000 acre-feet annually. However, the water-bearing material on the east side of the valley is probably more permeable than that on the west side, and to this extent the actual ground-water inflow may be somewhat greater than the computed inflow. As already indicated, only about one-third of this inflow is from the west.

In addition to underflow there is recharge by rainfall penetration, by artesian-well discharge, and possibly upward percolation of artesian water, and by surface water in the form of water applied in irrigation, waste drainage water, and stream flow. Discharge of the ground water is principally by evaporation and transpiration as the contours of the water table indicate little if any outward percolation. There is no known diversion of surface water out of the area.

As indicated on pages 245 and 246, recharge to the water table by rainfall penetration is a substantial quantity. As the capacity of the water-bearing material to absorb additional water where the capillary fringe reaches virtually to the surface is not known and as the texture of the soil and the amount and intensity of the rainfall range widely, it is not possible with the data available to estimate the amount of rainfall penetration. It is possible, however, to estimate roughly the quantity available for recharge by rainfall. The area enclosed by the 7,540-foot contour is approximately 160,000 acres. By assuming that the rainfall at Garnett, which was 7.93 inches in the calendar year of 1936, is representative of the rainfall within this area, the amount of rainfall was slightly more than 100,000 acre-feet.

In 1936 the discharge of artesian wells within the 7,540-foot contour, based on the artesian inventory was about 6,000 acre-feet. In addition there was leakage of the artesian wells underground and possibly upward percolation from the artesian aquifer. A part of this artesian water is undoubtedly disposed of by evaporation and transpiration, but a part of it produces recharge to the water table.

By using the evaporation and transpiration rate determined by White [27] for the Escalante Valley, Utah (p. 246)—that is, 2 acre-inches per acre where the depth to water is greater than 8 feet, 5 acre-inches per acre where it is from 5 to 8 feet, and 1 acre-foot per acre where it is less than 5 feet, it is possible to arrive at an estimate of the ground-water discharge. In July 1936 the depth to the water table was greater than 8 feet in about 18,000 acres, from 5 to 8 feet in about 69,000 acres and less than 5 feet in about 74,000 acres (pl. 5). On this basis the annual discharge of the ground water within the 7,540-foot contour would be about 100,000 acre-feet.

A recapitulation of the quantities involved in the recharge and discharge of the ground-water in the trough of the closed basin area shows that the recharge which can be attributed to percolation of unconfined water into the area and to water discharged by the flowing wells in the area is equal to only a small part, apparently less than one-fifth, of the ground-water discharge from the area.

It therefore appears that most of the recharge is due to rainfall penetration and inflow of surface water.

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[27] White, W. N., [illegible] by plants and evaporation from soil; Results of investigations in Escalante Valley, Utah: U. S. Geol. Survey Water-Supply Paper 659-A, pp. 87, 88, 1932.

TABLE 12.—*Pumping plants on wells in the San Luis Valley, Colo.*

No.	[illegible]	[illegible]	[illegible]	Depth [illegible]	[illegible] (inches) [illegible]	[illegible] amount of power [1]	[illegible] minute)	[illegible]
[illegible]	C. D. Wadsworth	[illegible]				G 6	300	
[illegible]	Frank Bennington	[illegible]						
[illegible]	[illegible]	[illegible]				G —	[illegible]	
[illegible]	[illegible]	1936		30-30			600	
[illegible]	[illegible]			25-41				Do.
[illegible]	[illegible]	1931		41	3 H		600	
[illegible]	[illegible]			45-45			1,150	
[illegible]	[illegible]	1931			4 H	4		
[illegible]	[illegible]	1934						
[illegible]	[illegible]	1934				G	1,100	
[illegible]	[illegible]	1934				G	1,150	
[illegible]	[illegible]	1931					1,050	
11J21M1	[illegible]	1931						
[illegible]	[illegible]	1932						Pumping plant not installed.
11J22E1	[illegible]				T	G 20		
[illegible]	[illegible]							Do.
[illegible]	[illegible]	1936		56				
[illegible]	[illegible]	1934				G	1,600	
[illegible]	[illegible]		16					
[illegible]	[illegible]		20		H			
[illegible]	[illegible]	1933	20			G	1,400	Pumping plant not installed.
[illegible]	[illegible]	1936	16					
[illegible]	[illegible]	1936	20					
[illegible]	[illegible]		20		H			
11J27G1	....do		18			20		
11J28M1	Union Central Life Ins. Co.		16		H		300	
[illegible]	Chester Mathias							Pumping plant not installed.
[illegible]	[illegible]	1936						
[illegible]	[illegible]				5 H			
[illegible]	[illegible]		20-16			G —	600	2 wells connected.
[illegible]	[illegible]		20					Pumping plant not installed.
[illegible]	[illegible]	1933				G —		
[illegible]	[illegible]	1936	16		3 H			
[illegible]	[illegible]				10 T	G 40		
[illegible]	[illegible]	1936	16					
11K2G1	[illegible]	1936	16			G	1,300	4 wells connected.
[illegible]	[illegible]	1934	16		H			2 wells connected.
[illegible]	[illegible]	1931	16	30	H	G		Do.
[illegible]	[illegible]	1936	16	30		G		
[illegible]	Ed. E. Oliver		20		H	20	700	
[illegible]	[illegible]	1936	22	40	6 V	G	700	
[illegible]	[illegible]		16		H			Pumping plant not installed.
[illegible]	[illegible]	1936	20		5 H			
[illegible]	[illegible]	1936	20		H			
[illegible]	[illegible]		20			G		
[illegible]	[illegible]		20			G		Pumping plant not installed.
[illegible]	[illegible]		20					
[illegible]	[illegible]		22	30		G		
[illegible]	[illegible]		16			G		
11K12Q1	[illegible]		16			G		Do.
11K13B1	[illegible]	1933						
[illegible]	[illegible]		20				1,150	Do.
[illegible]	[illegible]		20					Do.
[illegible]	[illegible]	1932	16	10				
[illegible]	[illegible]		20					
[illegible]	[illegible]		20	10			450	
[illegible]	[illegible]	1934		40		G	900	
[illegible]	[illegible]			40		G	1,300	Do.
[illegible]	[illegible]							Do.
[illegible]	[illegible]	1934	16					Do.
[illegible]	[illegible]	1934	16	30				
11K20M1	Jim Wilson		20					Do.
[illegible]	Joe Selters					G		
11K21Q1	[illegible]	1936		32				Do.
11K21M1	Mrs. Boyd		16	33	8 H		900	Do.
[illegible]	[illegible]	1936	20					
[illegible]	[illegible]		16		8 H		1,100	Pumping plant not installed.
[illegible]	[illegible]	1936	22					
[illegible]	[illegible]	1936	20	54			850	
[illegible]	[illegible]	1934		60			1,050	
[illegible]	[illegible]		20	40	6 H	G —	350	
[illegible]	[illegible]	1936	16			G —	600	
[illegible]	[illegible]	1934	24			G —		
[illegible]	[illegible]		20			G —		
[illegible]	[illegible]	1934		63			1,150	
[illegible]	[illegible]			50			1,150	2 wells connected.
[illegible]	[illegible]	1936	16					Do.
[illegible]	[illegible]		16		6 H			
[illegible]	[illegible]							4 wells connected.
[illegible]	[illegible]	1935		40			1,200	2 wells connected.
[illegible]	[illegible]	1935		40	8 H		1,200	
[illegible]	[illegible]			30				Do.
[illegible]	[illegible]		22	30				
[illegible]	[illegible]							Do.
[illegible]	[illegible]							Do.
[illegible]	[illegible]		16			E 10	1,050	Do.
[illegible]	[illegible]		16				800	Do.

[1] [illegible]

TABLE 12.—*Pumping plants on wells in the San Luis Valley, Colo.*—Continued

No.	Owner	Year completed	Diameter (inches)	Depth (feet)	Size (inches) and type of pump	Kind and amount of power	Reported discharge (gallons a minute)	Remarks
12J2K1	R. Sumner Love	1934	20		— T	G —	1,400	
12J2K2	do.	1931	20		— —	— —		
12J3B1	H. L. Clark	1936	20	[illegible]	— —	— —		Pumping plant removed.
12J5K1	A. O. Miller	1936	20	[illegible]	— T	G —	[illegible]	
12J[illegible]M1	George Gre[illegible]	1936	20		— —			Pumping plant not installed.
12J10G1	F. F. Long	1934	20	90	— T	G [illegible]	1,[illegible]	
12J10B1	Mervin Metz	1936	20		— T	G —		
12J10K1	F. L. Neff	1934	16	44	— T	G [illegible]		
12J11D1	Lester Hawkins		20	66	— T	G —	[illegible]	
12J11M1	do.	1934	16		— T	G 30	1,300	
12J12B1	Minnie Wright	1934	16	[illegible]	— T	G	1,300	
12J12D1	W. J. and Vern Sa[illegible]		20		8 H	G —	[illegible]	
12J12M1	Lyman Wright	1931	20		8 T	G	900	
12J14D1	Unknown				— T	G —	1,300	
12K2F1	George Hawkins		16		— V	G		
12K4B1	P. E. Harvey	1934	20		8 H	G —	1,050	
12K4K1	John V[illegible]	1936	16		8 H	G	....	
12K5K1	Fred Scheel	1934	18		— T	G —		
12K5N1	W. L. Gilbreath	1936	20		8 H	G —	1,300	2 wells connected.
12K6E1	Unknown				8 H	G —	1,300	
12K6G1	Bishop Estate	1936	20	63	— T	G —	600	
12K6M1	Roy David		16	63	10 T	G —		
12K6M2	do.	1936	20	36	8 H	G —	700	
12K7D1	Fred Scheel		16		8 H	G —	900	Do.
12K8D1	Warren Reynolds	1934	16		6 V	G	600	
12K9K1	Anna B. Wright	1933	16	34	6 H	G	800	Do.
12K9M1	Mr. Rawl[illegible]	1934	22		6 H	G		Do.
12K10N1	Frank A[illegible]craft	1936	20	33	6 H	G —		
12K11D1	R. E. Johns	1934	16	[illegible]	8 H	G	....	
12K11N1	W. D. Grant	1936	16	32	6 H	— —		Do.
12K11Q1	T. J. Baker	1931	16		6 H	G —		
12K12B1	C. E. Coker	1936		32	6 H	G 30		
12K12M1	Clem Sydenstricker	1934	16		6 H	— —		Pumping plant not installed.
12K13D1	G. E. Oxley	1934	20	40	6 H	G —	800	
12K14D1	Thea S[illegible]beck	1934	30		8 T	G	1,100	
12K15B1	J. S. Campbell ranch		16		16 T	G 30	1,300	
					8 H	G	1,350	2 wells connected.
12K15D1	William Mahl		16		6 H	G		2 wells connected.
12K16M1	Fred Wright		16		8 H	G	1,200	Do.
12K17Q1	Mr. Van Ostrand		16		8 H	G	1,200	
12K18E1	Ella Wesley	1936	20	42	8 T	G 30		
12K19D1	Unknown		16		6 H	G —	650	
12K22E1	A. G. Robertson		16	33	6 H	—	900	
12L5Q1	B. J. Terhorst	1936	16		6 H	G —		
12L6D1	Joe Selters	1936	16	32	6 H	G —		Do.
12L6K1	Fred Dunker	1931	16		6 H	G —	950	Do.
12L6M1	W. C. Gilmore	1931	16	30	6 H	E 7½		Do.
12L7A1	Jack Owsley	1932	15	[illegible]	6 H	G —	950	Do.
12L7E1	Warren Clark	1932	18	[illegible]	6 H	E 10	650	Do.
12L7H1	Pete Entz	1931	16	36	6 H	G —	750	
12L7K1	William Entz	1931	15	33	6 H	G	750	
12L7M1	Fred S[illegible]		30		5 H	G		
12L8B1	Mrs. F. Farnsworth	1932	16		8 H	G —	1,100	Do.
12L8M1	Jess Montgomery	1932	16		6 H	G		Do.
12L9D1	Frank Drake	1936	16		6 H	G —	750	Do.
12L10D1	Henry Stahl	1933	16-18	32-33	6 H	G	[illegible]	Do.
12L17B1	Clyde Entz	1936	16		5 H	G —	600	
12L18D1	Mr. Keck		16		6 H	G		
12L19F1	R. G. B[illegible]	1934	22	33	5 H	G	650	
12L19B1	W. G. Be[illegible]		22	32	8 H	G	900	Do.
12L19M1	Carl S[illegible]	1934	22	33	8 H	G	950	Do.
12L19K1	W. M. Fritz	1932	16	30	— —	— —	900	Pumping plant removed.
12L30D1	Herbert M. Bailey	1936	22		6 H			Pumping plant not installed.
12L30N1	C. E. Covey	[illegible]	22	[illegible]	6 H	G —	700	
13K19D1	C. G. Wright				6 H	G —		
13K19K1	W. R. R[illegible]		22	16	6 H	G	700	
13L18E1	Claud Thompson	1936	22	28	5 H	G 15		
13L19A1	Unknown		16		6 H	G	350	
14K14D1	H. O. Wagner			20	6 H	G —		
14K15F1	W. J. W[illegible]	1936	25	16	— H	G	100	
14K22K1	G. Schr[illegible]		25		— H	G —	300	
14K26L1	R. W. White		28		—	G —	100	
14K34G1	Whittier		40		— H	G —	550	
15K2L1	Herbert Winter		20	120	— —	G —	325	
15K12F1	Ed Knapp		13	48	— —	G —	200	
15K12N1	D. O. Meister		20		— —	G —	120	
15K12Q1	W. W. McElhinney		25	108	— H	G —	300	
15K24G1	J. H. Kelley		55		6 V	G —	900	
15L7N1	D. E. Ryker	1934	23	[illegible]	— H	G —	675	Well and buried drain connected.
15L18N3	J. K. E[illegible]		30		— —	G —	470	6 wells connected.
15L19E1	Forrest Kelley		48					

Confined or Artesian Water

Outline of Geologic and Artesian-water Conditions

General conditions.—The San Luis Valley is in the northern portion of the Rio Grande depression, described by Bryan in Section 1. The main part of the valley, north of the San Luis Hills, occupies an asymmetric structural basin in which has been deposited a large body of valley fill, with depositional contacts on the west side and a strong depression to the east and southeast on faults that are now concealed but are easily inferred. The lower part of the valley fill is considered to belong to the Santa Fe formation or its approximate equivalents of Pliocene age.

The name Santa Fe formation, used in this area by Siebenthal, is retained in the present description in

[illegible] of the older valley fill throughout the Rio Grande depression. The deposits in Colorado referred to as Santa Fe by Siebenthal and in this report are now mapped as the Hinsdale formation, which includes the Los Pinos member of dominantly sedimentary origin (see p. 208). The distinction probably has no hydrologic significance.

Resting unconformably on this older valley fill is the Alamosa formation, regarded by Siebenthal [28] as either late Pliocene or early Pleistocene. The Alamosa formation lies at the surface over almost the entire valley, and in its upper [illegible] part consists largely of sand and gravel, which contain the shallow ground water under water-table conditions that have already been described. At greater depths, however, this formation consists chiefly of alternating strata of sand and clay, the sand strata containing large quantities of water under artesian pressure. In the portion of the valley lying north of the San Luis Hills flowing wells can be obtained over an area of about 1,430 square miles, the greatest length of the area of artesian flow, from north to south, being about 66 miles and its greatest width about 32 miles (pl. 5). The numerous streams that enter the valley from the mountainous borders have built alluvial fans that coalesce along their margins and extend toward the interior of the valley, which is characterized by extreme flatness. The fans, especially in their upper parts, are underlain largely by gravel, but toward the interior of the valley the coarse material gives way largely to sand and clay.

Santa Fe formation.—The Santa Fe formation is exposed in basalt-capped mesas in the vicinity of Fort Garland and in a series of low hills extending from Trinchera Creek to San Pedro Mesa. On the west side of the valley the formation is represented by red sand and gravel about 300 feet thick with overlying basalt dipping gently eastward under the valley.[29] As seen in these exposures the Santa Fe formation consists of irregularly bedded sediments and associated lava flows. Its gravel beds are less regular and more cemented than those of the overlying Alamosa formation, and its clay beds are less continuous. It has undergone more deformation and hence its dips are more erratic.

In the southern part of the valley, where the top of the Santa Fe formation lies at or near the surface, several wells penetrated lava that is believed to be associated with this formation.

The Santa Fe formation probably underlies most of the valley and attains considerable thickness. In the trough of the valley, however, the Alamosa formation reaches its greatest thickness, and only a few wells have been drilled deep enough to possibly enter the Santa Fe formation. A test well,[30] 4½ miles east of Mosca, in the SW¼SE¼ sec. 5, T. 39 N., R. 11 E., was drilled in search of oil to a depth of 1,283 feet, apparently without reaching the bottom of the Alamosa formation. However, two other oil tests—one near Hooper and one near Mosca—may have passed through the Alamosa formation. These encountered flows of hot water below a depth of 2,100 feet, possibly in the Santa Fe formation. In these wells definite interpretation of the strata penetrated is not possible, because of lack of detail with which the different strata were reported.

The oil-test well, 10M27A1, located about 2 miles northeast of Hooper, was drilled to a depth of 4,308 feet, and a strong flow of hot water was encountered at a depth reported to be between 2,100 and 2,600 feet. This water has a temperature between 115 and 120 degrees. A similar discharge of hot water resulted from the test well 8 miles east of Mosca, in sec. 11, T. 39 N., R. 11 E., which was drilled in 1915 to a depth of 2,655 feet. According to the log, the well originally flowed 350 gallons a minute, from a depth between 2,200 and 2,655 feet, with a temperature of about 140 degrees.

The character of the formation at its outcrops indicates that the Santa Fe formation would probably not yield water as readily as the Alamosa formation. Sufficient evidence, however, has not yet been presented to entirely condemn it as a potential producer of water. Future prospecting for flowing wells outside of the present area of artesian flow may serve to clarify some of the questions that have arisen concerning possible artesian aquifers in the Santa Fe formation.

Alamosa formation.—The Alamosa formation forms a continuous blanket of sediments that mantle almost the entire valley. In the interior of the valley it consists of alternating beds of water-bearing sand and dense blue clays, but near the borders of the valley these beds are in part replaced by materials of coarser texture in the alluvial fans. The formation is best known from the logs of artesian wells.

The exact manner in which the sediments were deposited is not fully known. Siebenthal [31] believed that shore features were indicated by coarse material near the edges of the fans and that the preponderance of fine material in the interior of the valley, together with the persistence and continuity of these thin beds of sand and clay, were proofs of deposition in a relatively deep lake. He pointed out that wells in the interior of the valley show heavy clay beds and relatively few aquifers, whereas wells nearer the margin of the valley show thinner clay beds and more aquifers. Bryan has, however, reviewed the problem and has concluded that the

[illegible]

[illegible]

sediments are chiefly stream and wind deposits and that the valley has not been occupied by any deep permanent lake. He infers that the valley floor was lowered coincident with deposition, and that the beds were deposited on alluvial plains similar to those of the present on which temporary lakes may have existed. (See p. 217.)

The Alamosa formation consists largely of alternating beds of water-bearing sand and relatively impermeable clay that confines the water within the sand aquifers. Along the margins of the valley the strata are inclined toward the interior, and thus the water received in the higher parts of the alluvial slopes, largely from the mountains, is transmitted through the aquifers to lower parts of the valley. When the confining beds are penetrated by wells on the valley floor, water is encountered under sufficient hydrostatic pressure to produce flowing wells.

The number of beds of water-bearing sand encountered in the Alamosa formation differs from place to place. The sand strata range in general from about 1 to 20 feet in thickness, and are separated from one another by layers of blue clay ranging from a few feet to as much as a few hundred feet in thickness. As a general rule, the greatest number of water-bearing sands may be expected in the interior of the valley, where the sediments presumably reach their maximum thickness. Thus, a 3-inch well, drilled in 1931 at the Adams State Teachers College, in Alamosa, to a depth of 897 feet, was reported by Mr. Ray Wells, the driller, to have encountered 10 different flows; Siebenthal [32] records the log of a well in the southwest corner of the NE¼ sec. 9, T. 37 N., R. 9 E., 482 feet in depth, which encountered eight flows; and several other logs were recorded which encountered as many as 7 flows.

There is little regularity in the number of flows reported for wells that are drilled even in the same neighborhood. Since the use of rotary drilling equipment is almost universal in the valley, there is little doubt that many of the weaker flows are not reported in the logs. Thus, it is probable that in some logs every change in material is recorded, where in others only the stronger flows are recorded. On account of this lack of uniformity, any correlation of flows between wells is practically impossible, with the exception, perhaps of the first flow encountered.

Evidence has been presented to show that the shallow ground water and the artesian water have a common source. Along the edges of the valley and especially opposite the mouths of the canyons, the confining clay beds give way to sand and gravel, and this marginal strip, outside of the area of artesian flow, is the area of artesian recharge.

[32] Siebenthal, C. E., op. cit., p. 63.

Source of the Artesian Water

On account of the very nature of an artesian system, the artesian supply must come from water entering the higher portions of the system. All the requisites of an ideal artesian basin are present in the San Luis Valley. Water derived from mountain streams flows across the alluvial slopes bordering the valley, enters the alluvial fan deposits, and thence passes into the sand strata, which are overlain by the gently upturned confining clay beds. Some of the streams coming from the mountains to the east never get as far as the valley floor, while the volume of others is greatly reduced in flowing across the alluvial slopes. Some of the streams entering the valley from the west side are much larger than any of the east-side streams, and they also suffer losses in passing across the gravelly stretches of the alluvial slopes. Perennial streams, such as the Rio Grande and the Conejos, contribute substantial amounts of water to the artesian aquifers, either directly or by seepage of irrigation water. Much of the run-off carried by the minor streams on the west side is likewise available for artesian recharge, as the streams also lose water by seepage where they cross the coarse-textured material comprising the alluvial slopes.

By far the largest contributions to the supply of artesian water in recent years have come from seepage of the surface water that is used for irrigation, and the aggregate seepage loss is now much greater than it was under natural conditions before the water from the streams was diverted for irrigation. The resulting increase in the artesian head is explained on pages 260–261. Recharge of any artesian stratum is, however, confined to a belt along the margin of the valley that is not underlain by the confining bed of that stratum, and all artesian recharge is limited to the general marginal belt outside of the somewhat indefinite edge of the uppermost confining bed. In contrast, recharge of the shallow aquifer may occur by percolation to the water table in any part of the valley where the surficial material is at all permeable.

Water that falls as rain or snow on any part of the marginal belt of artesian intake may contribute to the artesian aquifers by penetrating to the water table. This process is closely allied to the building up of the water table by seepage from the streams and seepage of surface water after it has been diverted for irrigation. Owing to the complex nature of the several sources and the combination of effects governing the flow in the artesian aquifers, it is not practicable to isolate any one source from the others.

The available information indicates that under present conditions the water table is held at a high level in those parts of the artesian intake belt that are supplied by irrigation seepage and that this seepage is

the principal present source of artesian recharge; however, it also indicates that there is also substantial recharge of the artesian intake belt by seepage directly from the streams and by direct penetration of the rain and snow water.

Upper Confining Bed

The first artesian flow occurs at about 100 feet near Monte Vista, at about 175 feet near Parma, at about 250 feet in Alamosa, at about 125 feet in Blanca, at about 155 feet in Center, at about 175 feet in Garnett, at about 200 feet in Hooper and Mosca, and at about 115 feet in the vicinity of Swede Corners. Along the entire distance between Center and Hooper the first confining bed is struck between 80 and 90 feet. The railroad well at Moffat is reported to have encountered its first flow at 365 feet. The Nash well, in the SE¼NE¼ sec. 7, T. 43 N., R. 11 E., 6 miles due east of Moffat, had a reported depth of 520 feet to the first sand that produced a flow at the surface, but other sands with water under artesian pressure were probably encountered at higher levels. A group of wells at the State fish hatchery, half a mile south of La Jara, encountered the first flow at depths of 40 to 50 feet below the surface, the depth to the top of the clay being only about 30 feet. A well 2½ miles north of Manassa, in the NW¼NW¼ sec. 1, T. 34 N., R. 9 E., encountered its first flow at a depth of 60 feet.

Probably the most impressive evidence of the continuity and effectiveness of the upper confining bed is in the fact that nearly everywhere in the valley the water in the underlying aquifer is under sufficient head to rise above the level of the unconfined shallow water. The pattern of the confining bed may, however, be lenticular in character with the impermeable lenses overlapping and interlacing to the extent that any upward movement of the water is greatly impeded although not entirely prevented. Siebenthal[33] believed that the persistence of the upper confining bed is further demonstrated by the absence in the first underlying aquifer of alkaline water, such as the shallow ground water. However, as the water in this aquifer is under artesian head, it tends to move upward, thereby making downward percolation of alkaline water impossible, even if the confining bed is not entirely impermeable.

Insofar as is known, the only natural rupture in the confining bed in the central part of the valley discernible at the surface is at the Washington Springs, just north of the Denver & Rio Grande Western R. R., 7 miles east of Alamosa, in the northeast corner of sec 15, T. [illegible] N., R. 11 E. In [illegible] Siebenthal[illegible] estimated a flow of about 10 gallons a minute from the base of Hansen Bluff on the north side of the railroad and observed a pool on the top of one of the mounds that constitute the continuation of Hansen Bluff. No such discharge was visible in 1936, although vegetation adjacent to the bluff gave evidence that there was a small discharge of ground water at that point.

The failure of the flow of the Washington Springs was recognized by White[35] when he visited them in 1916. He attributed the failure of the springs to the well development that had been undertaken in the central and western parts of the adjacent townships in the 3 or 4 years previous to 1916, and mentioned the fact that the Hansen wells, located a few hundred feet from these springs, had almost ceased flowing. During the present investigation it was learned that the drilling of wells on the higher land east of Hansen Bluff materially diminished the flow of other wells and of Washington Springs. Conversely, when wells were plugged on the lower bench in the vicinity of Hansen Bluff, the wells upon the higher land became respectively stronger. The mutual interference between the flowing wells and the Washington Springs indicates that these springs are essentially artesian in origin. Siebenthal[36] mentions a spring mound on the lower land south of the railroad and in the same section as Washington Springs. When visited in the spring of 1936 the mound presented a hummocky surface with small round pools of standing water, but in the summer of 1936 there was no longer any water in the depressions, and it was necessary to dig a small hole in the mound to obtain a sample of water for analysis.

Permeability and Transmissibility of the Artesian Aquifers

In the present investigation tests were made by the method developed by Theis (p. 237) to determine the transmissibility of the artesian aquifers at five representative points in the valley. Although more such tests would have been desirable, the data obtained aided materially in making estimates of the rate at which water is transmitted by the aquifers. The tests were made on flowing wells already in existence. The procedure was as follows: (1) the static head of the water after the well had been closed for some time was measured, (2) the well was opened and allowed to flow for several days, and the discharge was measured as accurately as possible from time to time as a check on the uniformity of flow, (3) the well was again closed, and measurements of head were made periodically until it approached the original static head at the beginning of the test.

The equipment used in these tests was comparatively simple. Expanding soil plugs were used to close the

[illegible]

[illegible]

[illegible]

[illegible]

wells. A mercury-manometer pressure gage, developed by G. H. Taylor, of the United States Geological Survey, was connected to the end of the soil plug, and was used to measure the artesian head. The flow of all wells was small enough so that volumetric measurements could be made of their discharges by simply using a 5-gallon bucket and a stopwatch.

The essential data for each of the five wells that were used for transmissibility tests are presented in tables 13 and 14.

TABLE 13.—*Location and description of the artesian wells used for transmissibility determinations*

Well No.	Location	Diameter (inches)	Depth (feet)	Average discharge (gallons per minute)	Highest static head above land surface (feet)	Distance of measuring point above land surface (feet)	Period of test
9K6G1	11½ miles south of [illegible]	3	¹ 218.9	83.3	54.0	2.4	Oct. 6–10, 1936.
11M4B2	In town of Hooper ²	[illegible]	[illegible]	36.0	17.6	1.0	Oct. 22–28, 1936.
12K14R1	6 miles northeast of Monte Vista	2	¹ 172.6	18	15.1	1.5	Sept. 8–12, 1936.
14K25L1	2½ miles northwest of 15L6K1	[illegible]	¹ 118.2	28	7.4	.5	Sept. 9–25, 1936.
15L6K1	11 miles southwest of Alamosa	3	¹ 120.3	60	22.2	.5	Sept. 9–15, 1936.

¹ Measured depth, 1936.
² Garrison Mill & Elevator Co., well, U. S. Geol. Survey Water-Supply Paper 240, p. 85, 1910.

TABLE 14.—*Record of the static head of 5 artesian wells during the period of tests to determine transmissibility of the artesian aquifer*

9K6G1		11M4B2		12K14R1		14K25L1		15L6K1	
Time	Head (feet)	Time	Head (feet)	Time	Time (feet)	Time	Head (feet)	Time	Head (feet)
Oct. 6:		Oct. 23:		Sept. 8:		Sept. 14:		Sept. 10:	
4:35 p. m.	51.50	12:48 p. m.	44.35	3:19 p. m.	13.6	2:44 p. m.	6.90	11:26 a. m.	21.70
4:38 p. m.	51.50	12:54 p. m.	(²)	3:25 p. m.	13.6	2:54 p. m.	6.95	11:40 a. m.	21.70
4:48 p. m.	(¹)	Oct. 26:		3:27 p. m.	(¹)	3:01 p. m.	(¹)	12:04 p. m.	(¹)
Oct. 9:		1:42½ p. m.	(²)	Sept. 11:		Sept. 22:		Sept. 14:	
10:49 a. m.	(²)	1:43½ p. m.	36.10	10:46 a. m.	(²)	1:37 p. m.	(²)	11:24 a. m.	(²)
10:54 a. m.	47.00	1:44 p. m.	36.60	10:48 a. m.	8.60	1:39 p. m.	3.90	11:31 a. m.	13.95
10:56 a. m.	47.75	1:45 p. m.	37.00	10:49 a. m.	8.90	1:41 p. m.	4.15	11:33 a. m.	14.05
10:58 a. m.	48.15	1:46 p. m.	37.55	10:50 a. m.	9.10	1:43 p. m.	4.25	11:34 a. m.	14.25
11:00 a. m.	48.40	1:47 p. m.	37.80	10:51 a. m.	9.30	1:45 p. m.	4.40	11:36 a. m.	14.45
11:03 a. m.	48.80	1:48 p. m.	38.15	10:52 a. m.	9.40	1:47 p. m.	4.50	11:37 a. m.	14.55
11:06 a. m.	48.95	1:49 p. m.	38.35	10:53 a. m.	9.50	1:49 p. m.	4.55	11:38 a. m.	14.65
11:09 a. m.	49.10	1:50 p. m.	38.60	10:54 a. m.	9.60	1:51 p. m.	4.60	11:39 a. m.	14.75
11:12 a. m.	49.30	1:51 p. m.	38.70	10:55 a. m.	9.70	1:54 p. m.	4.75	11:40 a. m.	14.80
11:15 a. m.	49.40	1:52 p. m.	38.80	10:56 a. m.	9.90	1:57 p. m.	4.80	11:41 a. m.	14.95
11:20 a. m.	49.60	1:53 p. m.	38.95	10:57 a. m.	9.95	2:00 p. m.	4.85	11:42 a. m.	15.00
11:25 a. m.	49.70	1:54 p. m.	39.10	10:58 a. m.	10.00	2:03 p. m.	4.90	11:43 a. m.	15.05
11:30 a. m.	49.85	1:55 p. m.	39.20	10:59 a. m.	10.05	2:06 p. m.	4.95	11:44 a. m.	15.15
11:35 a. m.	49.95	1:57 p. m.	[illegible]	11:00 a. m.	10.10	2:10 p. m.	5.05	11:45 a. m.	15.25
11:40 a. m.	50.05	1:59 p. m.	39.70	11:05 a. m.	10.35	2:15 p. m.	5.10	11:46 a. m.	15.30
11:45 a. m.	50.15	2:01 p. m.	39.80	11:10 a. m.	10.50	2:20 p. m.	5.15	11:47 a. m.	15.35
11:50 a. m.	50.25	2:03 p. m.	39.90	11:15 a. m.	10.60	2:25 p. m.	5.20	11:49 a. m.	[illegible]
11:55 a. m.	50.35	2:05 p. m.	40.10	11:20 a. m.	10.75	2:30 p. m.	5.25	11:51 a. m.	15.55
12:00 M	50.40	2:08 p. m.	40.15	11:25 a. m.	10.90	2:40 p. m.	5.35	11:54 a. m.	15.70
12:10 p. m.	50.50	2:11 p. m.	40.20	11:30 a. m.	10.90	2:50 p. m.	5.45	11:57 a. m.	15.85
12:20 p. m.	50.60	2:14 p. m.	40.35	11:35 a. m.	11.00	3:00 p. m.	5.50	12:00 M	15.95
12:30 p. m.	50.70	2:17 p. m.	40.55	11:40 a. m.	11.00	3:10 p. m.	5.55	12:05 p. m.	16.10
12:45 p. m.	50.80	2:20 p. m.	40.65	11:45 a. m.	11.05	3:20 p. m.	5.60	12:10 p. m.	16.35
1:00 p. m.	50.90	2:23 p. m.	40.80	11:50 a. m.	11.10	3:30 p. m.	5.65	12:15 p. m.	16.45
1:15 p. m.	51.00	2:26 p. m.	40.90	11:55 a. m.	11.00	3:40 p. m.	5.70	12:20 p. m.	16.55
1:30 p. m.	51.05	2:30 p. m.	41.10	12:00 M	11.20	3:50 p. m.	5.75	12:25 p. m.	16.65
1:45 p. m.	51.10	2:35 p. m.	41.25	12:15 p. m.	11.30	4:00 p. m.	5.75	12:30 p. m.	16.85
2:00 p. m.	51.15	2:40 p. m.	41.40	12:30 p. m.	11.40	4:15 p. m.	5.75	12:35 p. m.	16.90
4:58 p. m.	51.25	2:45 p. m.	41.50	12:45 p. m.	11.45	4:30 p. m.	5.80	12:40 p. m.	17.00
5:05 p. m.	51.30	2:50 p. m.	41.65	1:00 p. m.	11.55	4:45 p. m.	5.85	12:45 p. m.	17.10
Oct. 10:		2:55 p. m.	41.80	1:15 p. m.	11.60	5:00 p. m.	5.90	12:50 p. m.	17.20
11:20 a. m.	51.60	3:00 p. m.	41.90	1:30 p. m.	11.70	5:15 p. m.	5.90	12:55 p. m.	17.25
11:26 a. m.	51.60	3:05 p. m.	42.00	1:45 p. m.	11.75	Sept. 23:		1:00 p. m.	17.30
		3:10 p. m.	42.10	2:00 p. m.	11.75	10:53 a. m.	6.45	1:10 p. m.	17.45
		3:15 p. m.	42.25	4:20 p. m.	12.10	11:00 a. m.	6.50	1:20 p. m.	17.60
		3:20 p. m.	42.30	4:25 p. m.	12.10	11:[illegible] a. m.	6.50	1:30 p. m.	17.70
		3:25 p. m.	42.40	4:30 p. m.	12.10	2:12 p. m.	6.53	1:40 p. m.	17.80
		3:30 p. m.	42.45	Sept. 12:		2:17 p. m.	6.55	1:50 p. m.	17.85
		3:40 p. m.	42.60	10:26 a. m.	12.55	5:31 p. m.	[illegible]	2:00 p. m.	17.95
		3:50 p. m.	42.70	10:30 a. m.	12.55	5:36 p. m.	6.60	4:05 p. m.	18.65
		4:00 p. m.	42.90	10:35 a. m.	12.60	Sept. 24:		4:10 p. m.	18.70
		4:15 p. m.	43.05	4:19 p. m.	12.60	12:07 p. m.	6.70	4:15 p. m.	18.75
		4:30 p. m.	43.20	4:25 p. m.	12.60	12:15 p. m.	6.70	4:20 p. m.	18.75
		4:45 p. m.	43.30			Sept. 25:		4:25 p. m.	18.75
		5:00 p. m.	43.40			4:54 p. m.	6.95	4:30 p. m.	18.80
		Oct. 27:				5:00 p. m.	7.00	Sept. 15:	
		10:23 a. m.	45.70					10:45 a. m.	20.35
		10:30 a. m.	45.70					10:50 a. m.	20.35
		4:04 p. m.	46.00					10:55 a. m.	20.35
		4:10 p. m.	46.00					11:00 a. m.	20.35
		Oct. 28:						4:[illegible] p. m.	20.55
		11:22 a. m.	[illegible]					4:[illegible] p. m.	20.55
		11:31 a. m.	46.65					4:[illegible] p. m.	20.55

¹ Well opened.
² Well closed.

The recovery equation of the Theis method involves only two variables—that of [illegible] and [illegible]. From the form of the equation the data for these two variables should plot as a straight line on semilog paper. It will be noted from figure 53 that, with the exception of well 11M4B2, all the points fall very close to a straight line. Measurements on this well, for the first few hours of recovery, fall to the left of the straight line determined from later measurements. It will also be noted that the [illegible] is not continuous—the points determined by measurements near the end of the test [illegible] to but on the left of the line for earlier measurements. It is not clear why all the points for this curve do not plot closer to a straight line, similar to the other curves. A possible explanation may be had from the performance of the well prior to shutting it for the recovery measurements.

The well had been closed in for about 6 months before the test. When the well was opened a large amount of fine sand and a small amount of clay were discharged with the water. The water also carried considerable inflammable gas. It was also noted, during this period of flow, that there was a definite surge of the discharge occurring at irregular intervals. The discharge of sand and clay may have increased the permeability of the material in the aquifer immediately surrounding the well. The static head, determined at the end of the test, was greater than that at the beginning of the test. These factors may have exerted some influence, whose effect is shown by the failure of the measurements to plot as a straight line.

As the head of an artesian well rises and falls in response to changes in barometric pressure (p. 261), all the measurements of head were corrected to a constant barometric pressure before plotting the recovery curve. In making the correction, it was assumed that the well was 100 percent efficient as a water barometer. The maximum water-level correction for barometric changes in pressure was only 0.23 feet, and most of the corrections were less than 0.10 foot.

Computations for the coefficient of transmissibility are simplified by using as s', the difference, from the curve, between the abscissas at the points where t/t' equals 1 and where t/t' equals 10. By doing this, the last term of the equation becomes equal to 1. The coefficients of transmissibility for the wells, computed on this basis are as follows: 9K6G1, 11,500; 11M4B2, between 1,800 and 2,300; 12K14R1, 3,800; 14K25E4, 7,800; 15L6K1, 5,300.

The average depth of the four wells (9K6G1, 12K14R1, 14K25E4, and 15L6K1) located on the west side of the valley, is about 160 feet, and their average coefficient of transmissibility is about 7,000. The four wells penetrate an average of 125 feet below the top of the first confining bed. On the basis of a thickness of 125 feet, the computed average permeability is 56, including the confining as well as the productive beds.

Head of the Artesian Water With Reference to the Land Surface

The pressure head of water at a given point in an aquifer is its hydrostatic pressure expressed as the height of a column of water that can be supported by the pressure. It is the height that a column of water rises in a tightly cased well that has no discharge.[37] During the course of the present investigation the heads of only a few wells were measured, partly because only a limited amount of time was apportioned for this phase of the work and partly because it was difficult to get permission from the well owner to close the wells on account of the possibility of injuring them. As most of the wells in the valley, except the city wells, are only partly cased, it is generally feared that any sudden changes produced by closing or opening the wells might cause the wells to cave, and thus to reduce their flow. No ill effects were noticeable after closing and opening the wells in the valley on which measurements of head were made.

During the investigation monthly measurements were made on 22 artesian wells. Of this number, 14 are on the Rio Grande alluvial fan, 6 are in the vicinity of Diamond Springs, in the southwestern part of the valley, and 2 are abandoned artesian wells in the closed basin area.

The wells on the Rio Grande alluvial fan either lacked sufficient head to flow at the surface or were intermittent, that is, flowing during only a part of the year. Three of the wells in the vicinity of Diamond Springs flowed, and these were shut in long enough to obtain measurements of head. The other three wells did not have sufficient head to flow, and hence their water levels were measured from the tops of the casings.

Tables 15 and 16 show all measurements that were made on artesian wells during 1936.

TABLE 15.—*Records of water levels in artesian wells of San Luis Valley*

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0.31	[illegible]	+1.18
[illegible]	+1.30		

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	7.15
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	7.73

[illegible]

[37] [illegible]

TABLE 15.—*Records of water levels in artesian wells of San Luis Valley*—Continued

11J2A1.—[illegible]

Date	Depth to water (feet)[1]	Date	Depth to water (feet)[1]
Apr. [illegible]	0.26	[illegible]	+1.39
[illegible]		[illegible]	+.31

11J13C1.—Mrs. J. C. Hynds. Domestic well, 2 inches in diameter, drilled 150 feet deep. Measuring point, top of casing 0.1 foot above land surface, altitude 7,082.70 feet.

Date	Depth to water (feet)[1]	Date	Depth to water (feet)[1]
Apr. 7, [illegible]	1.67	Sept. 18, 1936	0.26
June 5, 1936	(2)	Oct. 19, 1936	.06
July [illegible]		Nov. 16, 1936	.31
July 20, 1936	.41	Dec. 17, 1936	.99
Aug. 18, 1936	.52		

11J13R1.—Howard Macy. Stock well, 2 inches in diameter, bored 123 feet deep. Measuring point, top of casing 2.2 feet above land surface, altitude 7,680.68 feet.

Date	Depth to water (feet)	Date	Depth to water (feet)
Apr. 18, 1936	5.75	Sept. 18, 1936	[illegible]
May 5, 1936	3.72	Oct. 14, 1936	4.29
June 8, 1936	3.05	Nov. 16, 1936	4.55
July 20, 1936	4.33	Dec. 17, 1936	5.15
Aug. 18, 1936	4.68		

11J13R2.—Howard Macy. Stock well, 2 inches in diameter, bored 173 feet, deep. Measuring point, ½-inch reducer plug, top of casing 2.9 feet above land surface, altitude 7,681.43 feet.

Date	Depth to water (feet)	Date	Depth to water (feet)
Apr. 18, 1936	2.74	Sept. 18, 1936	1.57
May 5, 1936	2.11	Oct. 14, 1936	1.41
June 8, 1936	1.23	Nov. 16, 1936	[illegible]
July 20, 1936	1.77	Dec. 17, 1936	[illegible]
Aug. 18, 1936	1.89		

11J14P1.—J. H. Boats. Domestic well, 2 inches in diameter, bored 145 feet deep. Measuring point, top of lower valve seat of suction pump 2.0 feet above land surface.

Date	Depth to water (feet)	Date	Depth to water (feet)
Apr. 18, 1936	9.40	Sept. 18, 1936	7.12
May 5, 1936	8.11	Oct. 14, 1936	7.12
June 8, 1936	[illegible]	Nov. 16, 1936	7.48
July 20, 1936	7.09	Dec. 17, 1936	[illegible]
Aug. 18, 1936	7.32		

11J23H1.—Mrs. Anna McCormick. Domestic well, 4 inches in diameter, drilled 150½ feet deep. Measuring point, top of lower valve seat of suction pump 2.5 feet above land surface.

Date	Depth to water (feet)	Date	Depth to water (feet)
Apr. 18, 1936	8.11	Sept. 18, 1936	6.22
May 5, 1936	7.10	Oct. 14, 1936	6.19
June 8, 1936	5.72	Nov. 16, 1936	[illegible]
July 20, 1936	6.31	Dec. 17, 1936	[illegible]
Aug. 18, 1936	6.45		

[1] Plus sign preceding measurement indicates water level above measuring point.
[2] Reported by owner or tenant.

11J25R1.—Roy McConnell. Domestic well, 2 inches in diameter, drilled 207 feet deep. Measuring point, top of 2-inch union in the period Apr. 7 to July 19; on and [illegible] surface, altitude 7,682.81 feet.

Date	Depth to water (feet)	Date	Depth to water (feet)
Apr. 7, 1936	2.60	Aug. 18, 1936	1.05
May 5, 1936	1.78	[illegible]	[illegible]
June 8, 1936	.91	[illegible]	1.20
July 20, 1936	[3] 1.35		

11N32R1.—Unknown. Abandoned well, 2 inches in diameter. Measuring point, top of casing 1.0 feet above land surface.

Date	Depth to water (feet)	Date	Depth to water (feet)
Mar. 17, 1936	2.27	Aug. 14, 1937	[illegible]
Apr. 16, 1936	2.29	[illegible]	[illegible]
May 15, 1936	[illegible]	Oct. 13, 1936	[illegible]
June 13, 1936	[illegible]	Dec. 11, 1936	(4)
July 16, 1936	[illegible]		

12J12P1.—Lyman Wright. Stock well, 2 inches in diameter, drilled 138 feet deep. Measuring point, top of casing 0.2 foot above land surface, altitude, 7,681.74 feet.

Date	Depth to water (feet)	Date	Depth to water (feet)
Mar. 30, 1936	1.78	Aug. 17, 1936	0.12
Apr. 3, 1936	2.00	Sept. 17, 1936	.01
Apr. 17, 1936	1.76	[illegible]	[illegible]
May 5, 1936	1.23	Nov. 16, 1936	.41
June 8, 1936	.02	Dec. 17, 1937	[illegible]
July 17, 1937	.30		

12J13C1.—H. A. [illegible]. Stock well, 2 inches in diameter, drilled [illegible] feet deep. Measuring point, top of casing at land surface, altitude 7,680.[illegible] feet.

Date	Depth to water (feet)
Apr. 3, 1936	0.81
July 17, 1936	+.85

12J26D1.—Frank C. Seyfried. Domestic well, 2 inches in diameter, drilled 168 feet deep. Measuring point, top of casing 0.5 foot above land surface.

Date	Depth to water (feet)[1]	Date	Depth to water (feet)
Apr. 10, 1936	2.90	Sept. 17, 1936	0.38
May 5, 1936	1.68	Oct. 14, 1936	.79
June 8, 1936	+.17	Nov. 16, 1936	1.13
Aug. 17, 1936	.04		

12K6C1.—Van Ostrand. Stock well, 2 inches in diameter, drilled 150 feet deep. Measuring point, top of 8-inch galvanized iron extension to 2-inch casing 5.5 feet above land surface, altitude 7,677.89 feet.

Date	Depth to water (feet)	Date	Depth to water (feet)
July 10, 1936	[5] 1.46	Aug. 25, 1936	1.56
July 2[illegible], 1936	1.75	Sept. 1, 1936	1.47
July 24, 1936	1.82	Sept. 8, 1936	1.33
July 27, 1936	1.90	Sept. 15, 1936	[illegible]
July 28, 1936	1.91	Sept. 22, 1936	1.22
Aug. 3, 1936	1.81	[illegible]	1.15
Aug. 10, 1936	1.61	[illegible]	1.14
Aug. 17, 1936	1.77	Oct. 13, 1936	[6] 1.23

[1] [illegible] measuring point.
[3] New measuring point, [illegible]
[4] [illegible]
[5] Water-stage recorder [illegible]
[6] Water-stage recorder removed.

TABLE 15.—[illegible] *Valley*—Continued

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	.81	[illegible]	.32
[illegible]	.67	[illegible]	[illegible]
[illegible]	.53	[illegible]	[illegible]
Sept. 1, 19[illegible]	[illegible]	[illegible]	.40
Sept. 8, 1936	[illegible]	[illegible]	.67
[illegible]	[illegible]	[illegible]	1.69

[illegible]

[illegible]	[illegible]	[illegible]	1.71
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible] 10, 1936	1.59
[illegible]	[illegible]	[illegible] 10, 1936	1.48
[illegible]	[illegible]		

[illegible]

[illegible]	[illegible]	[illegible]	Depth [illegible]
[illegible]	[illegible]	July 23, 1936	[illegible]
[illegible]	4.46	Aug. 19, 1936	5.82
[illegible]	[illegible]		

[illegible]

June 6, 1936	1.47	Sept. 21, 1936	1.63
June 10, 1936	1.41	Oct. 15, 1936	1.58
[illegible]	[illegible]	Nov. 18, 1936	1.69
[illegible]	[illegible]	Dec. 16, 1936	1.70

16L31A1.—Tennis Smith. Stock well, 2 inches in diameter. Measuring point, top of highest part of casing, west side, 0.5 foot above land surface.

[illegible]	[illegible]	[illegible]	+7.33
[illegible]	[illegible]	[illegible]	+7.15
[illegible]	[illegible]	[illegible]	+7.20

16L32P1.—Frank Morgan. Domestic and stock well, 2 inches in diameter, 61 feet [illegible]

Date	Depth to water (feet)	Date	Depth to water (feet)
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
July 23, 1936	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		

[illegible]

[illegible]	0.88	Sept. 21, 1936	[illegible]
[illegible]	+1.60	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	+.57
[illegible]	+.70	[illegible]	+.61

[illegible] deep. Measuring point, top of ¾-inch plug 0.2 foot above land surface.

[illegible]	[illegible]	Sept. 21, 1936	+1.35
[illegible]	[illegible]	[illegible]	+.93
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

TABLE 16.—*Head of water in certain artesian wells and of McIntire Springs, San Luis Valley, Colo.*

[illegible]	Location	[illegible]	Measured artesian head with reference to the land surface [illegible]	Approximate [illegible] with reference [illegible] level
[illegible]	[illegible]	7,591	[illegible]	[illegible]
[illegible]	[illegible] west from Center.	7,672	[illegible]	7,673
[illegible]	[illegible]	7,557	18.0	[illegible]
12J12P1	4 miles north of Monte [illegible]	7,675	[illegible]	7,675
12K6C1	[illegible] Vista.	7,666	4.0	7,670
[illegible]	6 miles northeast of Monte Vista.	7,615	15.0	7,630
[illegible]	12 miles east and 7 miles north from Alamosa.	7,700	14.1+	7,714+
[illegible]	[illegible] mosa.	7,572	[illegible]	7,585+
14K25E1	2½ miles northwest of 15L6K1.	7,619	7.5	7,627
[illegible]	"Bucher Well" in Alamosa.	7,530	[2] 62.0	7,592
[illegible]	[illegible]	7,746	6.0	7,752
[illegible]	11 miles southwest of Alamosa.	7,615	22.0	7,637
[illegible]	[illegible]	7,601	16.5+	7,617+
[illegible]	[illegible] Jara.	7,642	[illegible]	7,650
[illegible]	[illegible]	7,590	5.0	7,595
16N18E1	McIntire Springs	7,520±	0	7,520±
17L23J1	At west edge of Manassa.	[illegible]	[illegible]	7,680±

[1] Based on topographic map of San Luis Valley, U. S. Geol. Survey Water-Supply Paper 240, pl. 1, 1906.
[2] Reported measurement.

The highest head measured in 1936 was that of a 3-inch well (9K6G1) owned by Victor Crow, about 11½ miles south of Saguache. After being closed in connection with a transmissibility test (table 14) the head in this well built up to 54 feet with reference to the land surface, at which point it was about at equilibrium. The head on well 11M4B2, at Hooper, as measured, was somewhat over 47 feet. The five wells recorded in table 14 are the only ones on which pressure measurements were made over a sufficiently long shut-in period to insure essentially complete equilibrium conditions. Measurements of head were made on a number of other wells, but the readings were generally taken after only short intervals of shut-in, when equilibrium conditions had probably not yet been fully reached.

At La Jara a well (16L14P1) was drilled in September 1936 to be used as a water supply for the Consolidated School there. It was drilled to a depth of 283.5 feet and was cased with 4-inch casing to 200 feet. A. R. Martin, of Sanford, the driller, reported that flows were encountered at practically every 20-foot interval below a depth of 60 feet, with the possible exception of the 220-foot horizon. The well was supplied from flows at approximately the 240, 260, and 280-foot horizons, which increased in strength with depth. Upon completion, the well was allowed to flow without reduction for a period of 8 days, following a practice common among drillers in the valley to give the well an opportunity to clean itself of sand and to create a cavity at the bottom. On October 3, 1936, it had a measured discharge of 125 gallons per minute. The well was shut

in at 11:20 a. m., and by 1:22 p. m., the head was 15.95 feet with reference to the top of the casing, or about 16.5 feet with reference to the land surface, which was probably still a little below the head at complete equilibrium.

Well 13Q30R1, on the Stone ranch, about 9 miles northeast of Alamosa, was shut in during a 7-minute interval. The initial measured head was 9.2 feet and the final one 10.5 feet with reference to the top of the casing, or 12.5 feet with reference to the land surface. This well is 3 inches in diameter and had a measured flow of 24 gallons a minute. Well 13Q2N1, owned by C. M. King, 12 miles east and 7 miles north from Alamosa, on land formerly belonging to the Calkins ranch, had a head of 14.1 feet with reference to the land surface after having been shut in for 4 minutes. The well is 2 inches in diameter and had a measured flow of 7 gallons a minute.

The "Bucher" well, 14M10A1, on the east side of the river at Alamosa, taps an aquifer at a depth of approximately 932 feet and is one of the oldest and deepest wells drilled for artesian water in the valley. The owner reported that a gage on the well recently showed a pressure of 27 pounds to the square inch, which would be equal to a water level 62.3 feet above the point of measurement. Siebenthal [38] states that in 1891 Carpenter reported a head of 56 feet. This difference may be due to an increase in pressure, or to differences in the calibration of the gages used.

As a general rule, the head in any locality increases somewhat with the depths of the successive sands. As explained by Siebenthal, this range in head is due in part to interference of a greater number of wells tapping the shallower artesian strata. It is probable, however, that there was an original range in head with depth. Beneath the center of the valley the artesian beds are nearly level, but near the margins they slope upward. Near the outer limits of the basin the confining members of the upper flows feather out and are replaced by sand and gravel. Presumably the confining beds of the lower aquifers extend farther up the slope, and as their intake areas are successively higher, their heads are respectively greater.

The map (pl. 5) shows the area of artesian flow in the San Luis Valley—that is, the area in which the artesian water is under sufficient pressure to rise to the top of the wells and overflow upon the land surface. This area includes the entire interior part of the valley and in some places extends considerably up on the alluvial slopes. In 1936 it covered about 1,430 square miles.

On the east side of the valley the occurrence of five flowing wells in Blanca, drilled after Siebenthal's report was written, has increased the known area of flow. White,[39] in his report on the valley, written in 1916, recognized the possibility of an extension of the area of flow to the east, and raised the question as to whether the Blanca area is separated from the main area of artesian flow. Although there is insufficient information to answer this question definitely, the available evidence indicates it to be a separate area of flow, somewhat as shown on the map. It is possible that the artesian aquifers at Blanca are separated from those of the main artesian basin to the west. It is known that two farms on the highway 3 miles northwest of Blanca depend solely upon shallow wells for their domestic supply. There are no artesian wells between Blanca and baldy station, 6 miles west, but west and north of Baldy station there are several nonflowing artesian wells.

Hydraulic Gradients and Direction of Movement of the Artesian Water

The data on head in table 16 show that the movement of the artesian water is from the sides of the valley toward the interior. Thus the head with reference to sea level is 7,645 feet in well 9K6G1, and 7,605 feet in well 11M4B2, 18½ miles southeast, giving a gradient between these points of 2.1 feet to the mile. The head is 7,673 feet in well 10J27A1 and 7,605 feet in well 11M4B2, 16½ miles east, giving a gradient from west to east of 4.1 feet to the mile. Thus also the difference in head between well 12J12P1 and well 11M4B2 is 70 feet in a distance of 17 miles, or a gradient in a northeast direction of 4.1 feet to the mile. The gradients in any one artesian bed are probably somewhat greater than these figures, as well 11M4B2 is 740 feet deep and those used for comparison are only between 135 and 220 feet deep. It is known that the artesian head in any locality increases with depth. No data were available on measurements of head along the northeast edge of the valley, but it is not unreasonable to assume that the movement of water would be toward the center of the valley. On the east side of the valley, however, two measurements of head indicate the following relationship. Between well 13Q2N1 and well 14M10A1 (the Bucher well at Alamosa), the difference of head is 122 feet in a distance of 14 miles, indicating a gradient toward the center of the valley of 8.7 feet to the mile. Here again the actual gradient is probably somewhat larger, as the Bucher well is among the deepest in the valley and has the highest known head above land surface. The head of well 13Q30R1 is 129 feet lower than that of well 13Q2N1, 5½ miles northeast, indicating a gradient to the southwest of 23.4 feet to the mile. The recorded head of well

[38] Siebenthal, C. E., op. cit., p. 57.

[39] White, W. N., The San Luis Valley, Colorado, [illegible] and general [illegible] problems [illegible]. Manuscript copy in files of Conservation Branch, U. S. Geol. Survey, 1916.

13Q30R1, located [illegible] miles [illegible] of Alamosa, is 7 feet lower than that of well 14M10A1, at Alamosa. This is explainable from three different angles: First, well 13Q30R1 was shut in only 7 minutes when the measurements were made and equilibrium had not been reached by a wide margin; secondly, Alamosa is west of the trough of the valley and the head there is undoubtedly influenced by inflow from the west; and finally, the aquifer supplying well 14M10A1 is over 900 feet below the surface, whereas well 13Q30R1 is a shallow well, probably less than 250 feet deep. Of all the wells measured in the valley, well 14S14Q1, at Blanca, had the highest head with reference to sea level. If there is a connection between the artesian water at Blanca and that in the trough of the valley, the difference in head at Blanca and at Alamosa indicates a hydraulic gradient toward the trough of the valley.

In the portion of the valley lying south of the Rio Grande the movement of water is in general toward the trough of the valley. Between well 14K25E4 and well 14M10A1 there is a difference in head, with reference to sea level, of 35 feet in 11½ miles, or a gradient of 3 feet to the mile in an east direction. Between well 14K25E4 and well 16L14P1, at La Jara, 12 miles southeast, the gradient is about 1 foot to the mile. In the 4-mile stretch between well 16L31A1 and well 16L14P1, at La Jara, there is a difference in head of 33 feet, or a gradient in a northeast direction of 8.2 feet to the mile.

The lowest head with reference to sea level given in the table is that of McIntire Springs (16N18E1), and with the possible exception of Dexter Spring, mentioned by Siebenthal,[40] this is the lowest head of record in the valley. Although Dexter Spring was not identified in 1936, Siebenthal's topographic map indicates that it was lower than McIntire Springs. The movement of water in the southwestern part of the valley is in the direction of the three springs, as is shown by the gradients from two points, one southwest and the other west of the Springs. The difference in head between well [illegible], at the west edge of Manassa, and McIntire Springs is 160 feet in a distance of 10 miles, giving an average gradient of 16 feet to the mile. The difference between well 16L14P1, at La Jara, and McIntire Springs is 97 feet in a distance of 8 miles, or an average eastward gradient of 12 feet to the mile. The steepest [illegible] that between well 16M24L1 and McIntire Springs, the difference in head being [illegible] feet in [illegible] miles, giving a northeast gradient of 30 feet to the mile. Any suggestion that there may be underflow [illegible] of the valley passing around the south end of the San Luis Hills is precluded by the differences in heads between the well at Manassa and the well at La Jara, and between these wells and McIntire Springs.

In the northern half of the valley there is a gentle southward gradient. Thus between well 11M4B2 at Hooper and well 14M10A1 at Alamosa, both of which are deep wells, the difference in head is 13 feet in 19 miles, giving an average gradient of 0.7 foot to the mile. From Alamosa southward to McIntire Springs the gradient increases, the difference in head between well 14M10A1 at Alamosa and McIntire Springs being 70 feet in 13 miles, giving an average southward gradient of 5.4 feet to the mile.

The comparison of the water-surface altitudes of these several representative wells shows rather conclusively that north of the Rio Grande the water moves laterally from the sides of the valley toward the trough. In the trough of the valley the movement of water is southward, following the gentle gradient in that direction. South of the Rio Grande the water moves from the west side of the valley in an eastward direction, the lowest head being in the neighborhood of McIntire Springs.

Fluctuations of Artesian Head

Increase in head produced by irrigation.—Contrary to the usual history of similar artesian basins, the area of artesian flow in the San Luis Valley has increased rather than diminished over a period of development in the last 30 years. The map of the valley (pl. 5) shows the area of flow as delimited by Siebenthal[41] in 1906 and that which was determined by field work in 1936. It shows that in this 30-year period the area of flow has expanded somewhat on the west, south, and east sides of the valley. The increase is quite evident on the gentler alluvial slopes, such as the Rio Grande fan, but not where the slopes are steep.

Along the west side of the Rio Grande alluvial fan the boundary of the area of flow has moved westward, in some places a distance of over a mile. In the vicinity of Manassa, it has moved southward about 2 miles. A well drilled in 1925 at the west edge of Manassa, in the NE¼SE¼ sec. 23, T. 34 N., R. 9 E., lacked only about 10 inches of flowing at the surface. East of the Baca Grant and in the area south of it, a lack of control in the form of nonflowing wells made the interpretation of the limit of flow less accurate than in most other parts of the valley, but according to the best available data the limit of flow conforms nearly to that shown by Siebenthal in 1906. There is little doubt that flowing wells could have been obtained in the vicinity of Blanca in 1906, but Siebenthal's map was compiled before there was any drilling in that area.

To explain this increase in the area of flow it is necessary to consider the history of irrigation development in the valley. Early development occurred in the central part of the valley, north of the Rio Grande,

[illegible]

in the vicinity of Hooper and Mosca, but as the gravelly land to the west was found to be fertile and suited to cultivation, the development extended westward. On account of a concentration of alkali in the soil, the lands first cultivated were abandoned gradually in favor of the better-drained, gravelly soils on the west side of the valley, both north and south of the Rio Grande. With the development of this area and the consequent increase in surface water diversion, there occurred an increase in artesian-water recharge and consequently an increase in artesian head and an expansion of the area of artesian flow.

Decrease in head produced by mutual interference of artesian wells. During the course of the artesian-well inventory well owners often reported that the flows of their wells were materially reduced when wells tapping the same flow were drilled in the locality. Probably the chief cause of gradual failure of wells is mutual interference, especially in the larger towns of the valley, where the interference has resulted in drilling to deeper aquifers that are tapped by fewer wells. Even as far back as 1906 the numerous wells in Monte Vista so seriously affected one another that the head had been reduced to about half the original head. Similar overtaxing of the shallower artesian aquifers in Alamosa has resulted in the drilling of a number of wells to aquifers below 800 feet. In 1936 neither the head nor the flow of these deep wells had yet been seriously impaired.

In several places the area of flow did not extend up the slope quite as far in 1936 as was shown by Siebenthal. Probably most of these slight differences are due to lack of control in mapping the limit of flow in 1906, but in at least one locality there has been an actual decrease of the area of flow. Thus two wells on land formerly known as the Calkin's Ranch, in sec. 1, T. 38 N., R. 12 E., and reported by him as flowing wells, were not flowing when seen in 1936, probably because of the interference of wells in the central and western parts of the township. The cessation of the flow of Washington Springs may also be attributed to the drilling of wells.

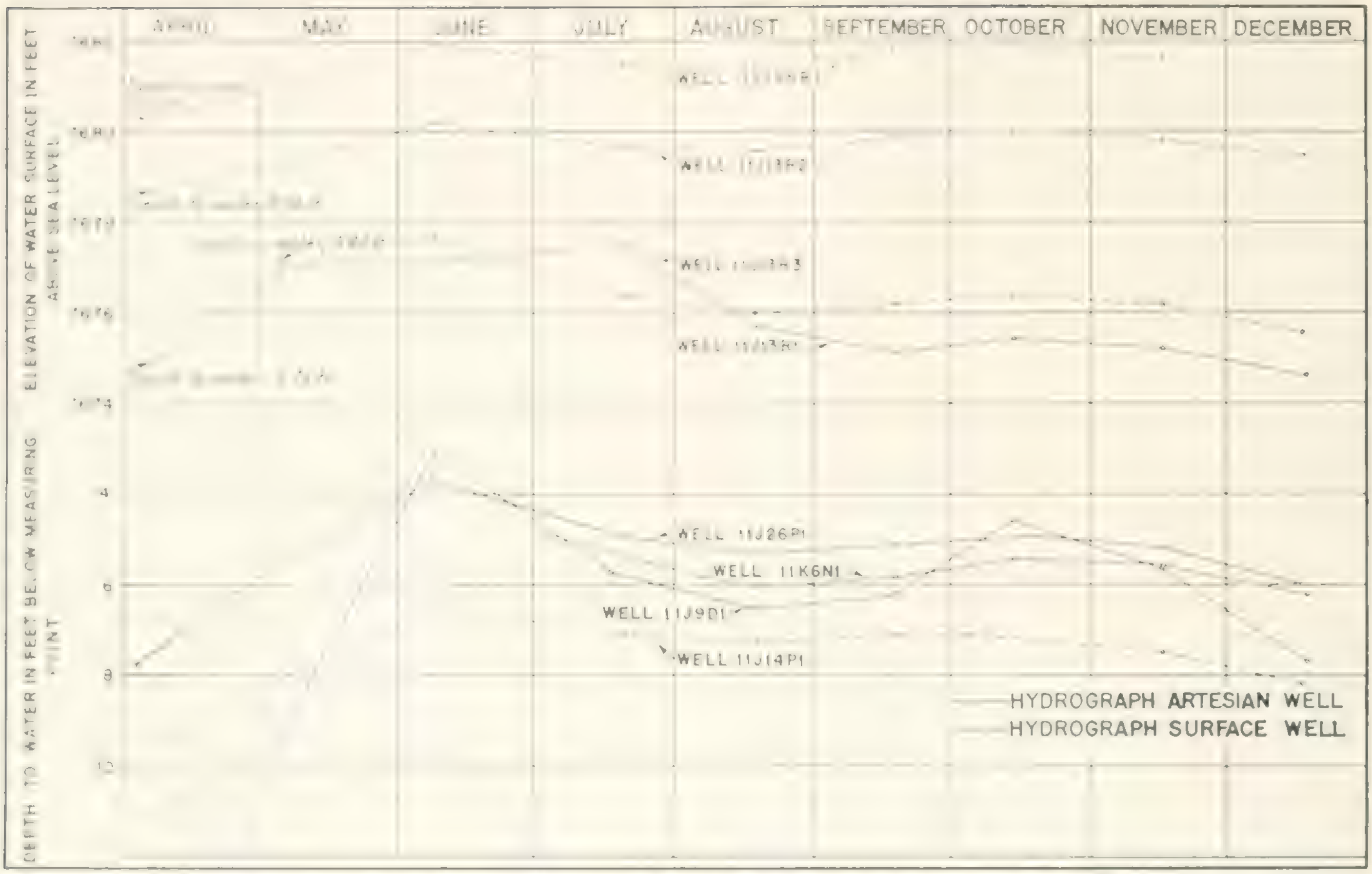
Seasonal fluctuations.—Near the boundary of the area of flow there is a definite variation in artesian head during the year. Of the wells on the Rio Grande alluvial fan, on which periodic measurements were made (table 15), some are located approximately on the boundary of the area of flow and others outside the area of flow. Those which are located about on the line usually flow during the late spring, summer, and early fall—the period of flow about coinciding with the irrigation season. A common expression in the valley is that the artesian wells "come up with the sub" and "go down with the sub." These seasonal fluctuations are due to the seasonal rise and fall of the water table in the artesian intake belt and probably also in part to the seasonal loading and unloading of the artesian aquifers as the water table above the upper confining bed rises and falls.[42] Figure 55 shows the relation between the water levels in four artesian wells and four shallow wells with water-table conditions on the Rio Grande alluvial fan. It shows that the rise and fall of the water levels in the artesian wells occur at about the same time as the rise and fall in the shallow wells. The maximum fluctuation in water level observed during 1936 was 3.07 feet, in well 12J26D1, located south of the Rio Grande near Monte Vista, but in most of the artesian wells on the Rio Grande alluvial fan the fluctuation was about 2 feet. The flowing wells at some distance from the boundary of the area of flow and outside of the irrigation districts appear to have comparatively small seasonal fluctuations in head.

Barometric fluctuations.—The water level in an artesian well generally falls as the atmospheric pressure increases and rises as the atmospheric pressure decreases. The magnitude of this type of fluctuation is dependent upon the amount of variation in atmospheric pressure and upon the degree to which the well acts as a water barometer. The fluctuations of the water level produced by barometric fluctuations and other causes combined are shown in figure 56. A 7-day automatic water-stage recorder was installed on an artesian well, 12K6C1, located about 6 miles north of Monte Vista, just inside the area of flow. The well, which was 2 inches in diameter and 150 feet in depth, was adapted above land surface to accommodate the recorder. Hourly barometric readings were obtained from the Alamosa plant of the Public Service Co. of Colorado, 20 miles distant, and after being converted to feet of water, were plotted to the same scale as the hydrograph on the recorder chart. The record for the week of September 8 to 15, 1936, has been reproduced in this figure. In the first 4 days of the week the fluctuations of the water surface in the well were of about the same nature as the fluctuations of the atmospheric pressure at Alamosa. In the latter part of the week the agreement is not quite so close, probably in part because of effects of irrigation and possibly in part because of difference in the barometric pressure at Alamosa and at the well.

Discharge of Artesian Water

Artesian springs.—In the San Luis Valley there are several artesian springs situated near the limit of flow. Washington Springs, near the trough of the valley, are the only known springs that do no occur along the margins of the valley. In all these springs the temperature of the water is comparable to that of the shallow artesian water in the vicinity of the springs.

[42] Meinzer, O. E., Compressibility and elasticity of artesian aquifers: Econ. Geology, vol. 23, pp. 275-276, 1928.



Among the large springs in the valley are the McIntire Springs, on the south side of the Conejos River, in the NW¼ sec. 18, T. 35 N., R. 11 E. They rise along the Conejos River at the base of the San Luis Hills at the contact between the Alamosa formation and the volcanics of the San Luis Hills. According to Siebenthal[43] this is probably a fault contact. Confined water moving southeastward in the Alamosa formation comes up along the contact and through the volcanics and escapes at the surface as the McIntire Springs. In addition, there are many small springs along the Conejos River which are probably supplied from water-bearing beds of the Alamosa formation where they abut against the volcanics. In the course of the present investigation the discharge of McIntire Springs was measured four times, using a Price current meter, and was found to be nearly the same each time (see table 17).

Depressions in the margins of the confining beds of the artesian aquifer afford opportunities for the artesian water to spill over the lip of the confining member, forming springs. Springs of this type occur in depressions along the west side of the San Luis Valley. Their discharge may be called artesian reject, as it represents the overflow of the artesian aquifer.

Diamond Springs, which are the largest springs of this type, emerge on low ground south of a meandering distributary from La Jara Creek, in the N½ sec. 31, T. 35 N., R. 9 E. The swampy tract from which the springs emerge covers 160 acres and is characterized by a dense growth of tules, with bodies of water that denote the locations of the different spring openings. The discharge of these springs has increased progressively during the last 30 years, and at the present time it is many times that when first noted. Thirty years ago the spring area had little if any outflow, whereas the average of three measurements in 1936 amounted to about 24.5 second-feet. W. D. Carroll,[44] irrigation division engineer for the State of Colorado, stationed at Alamosa, reported that the flow of these springs was very small 30 years ago, probably not over a quarter of a second-foot, but that the flow began to increase materially about 1916 and has continued to increase since then. Siebenthal[45] makes no mention of these springs in his discussion of springs in the valley. Had they been of consequence at that time he undoubtedly would have reported them, especially in view of the fact that he located an artesian well only a quarter of a mile

[43] [illegible]

[44] [illegible]

[45] Siebenthal, C. E., op. cit., pl. 1.

east of the spring area. These springs give convincing evidence in support of the theory that there has been considerable increase in recharge of the artesian aquifers on account of the application of surface water for irrigation on the alluvial slopes.

Another group of springs on the west side of the valley, in sec. 12, T. 37 N., R. 7 E., are the source of Spring Creek, a small perennial stream flowing eastward to the valley floor. The measured flow of Spring Creek in November 1936 was 9.74 second-feet. Four other measurements by Dan Jones, deputy State hydrographer, are available, but as they were made in 1928 and 1929 they were not included in the table. They are as follows: April 11, 1928, 14.2 second-feet; January 15, 1929, 12.9 second-feet; March 16, 1929, 13.7 second-feet; and February 18, 1929, 13.2 second-feet. Russell Springs, located on the northwest margin of the valley, in the NE¼ sec. 23, T. 43 N., R. 7 E., are the main source of supply for a series of interconnected lakes known as Russell Lakes, about 2 miles east of the point where the springs emerge. As they are located on the boundary of the area of artesian flow, these springs also represent artesian reject. When measured in November 1936 they were flowing 3.6 second-feet. Both Russell Springs and those which furnish Spring Creek are situated at points along the margin of the valley, topographically lower than the adjacent land surface. Unlike Diamond Springs, however, these two springs are not the result of irrigation development but have been permanent within the memory of white man.

The results of measurement in 1936 of the discharge of the principal springs in the valley are given in the following table. The total discharge of the artesian springs in 1936 is estimated to average 65 second-feet, or 47,450 acre-feet in the year.

TABLE 17.—*Discharge measurements of artesian springs in the San Luis Valley*

Number	Name	Date of measurement	Discharge (second-feet)	Average discharge (second-feet)
[illegible]	Russell Springs	Nov. 23, 1936	3.60	3.60
[illegible]	Spring Creek	Nov. 27, 1936	9.74	[illegible]
14N15A1	Washington Springs			
14N15G1	Spring Mountain and Washington Springs.		(1)	
[illegible]	Diamond Springs	Apr. 14, 1936	19.29	
		May 6, 1936	27.69	
		June 3, 1936	26.52	24.50
[illegible]	[illegible] springs	Mar. 27, 1936	19.78	
		May 12, 1936	18.44	
		June 3, 1936	18.47	
		July 11, 1936	18.97	18.92
	Estimated discharge of smaller springs.			9.0±
	Total			[illegible]

1 Trickle.

Flowing wells.—In order to determine the quantity of artesian water discharged annually in the San Luis Valley an inventory was made of the flowing artesian

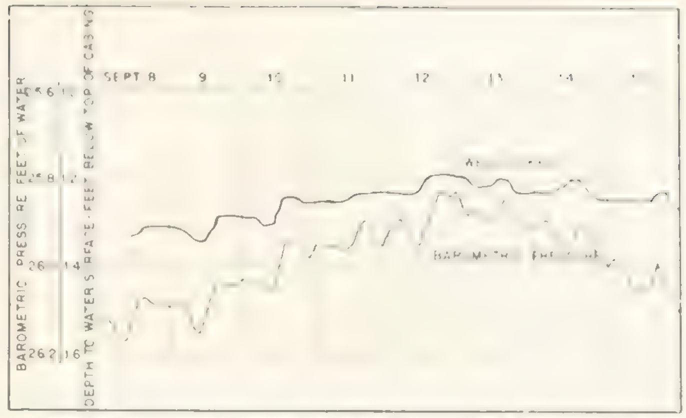


FIGURE 16.—Fluctuation of water level in well 12K[illegible] and [illegible] barometric pressure at Alamosa, September 8–15, 1936.

wells. On account of the lack of time, it was not possible to visit and record every well in the valley. In certain restricted areas the wells in every section were located and measured, but over most of the area, only the wells in the odd-numbered sections were recorded. In connection with the study of water requirements in the Carmel-Bowen area by the Bureau of Agricultural Engineering (see pl. 11), it was necessary to know the total annual discharge of all artesian wells in that area. Accordingly, every well in that area was located and the discharge of each measured. Approximately 32 square miles, lying between the Monte Vista and the Empire canals, were included in this complete inventory, which covered parts of Tps. 36 and 37 N., R. 8 E., and smaller parts of Tps. 36 and 37 N., R. 9 E.

The following townships on the east side of the valley were completely inventoried—that is, every well in each section was located and measured: T. 41 N., R. 11 E.; about 9 sections of T. 41 N., R. 12 E.; T. 40 N., R. 11 E.; T. 40 N., R. 12 E.; T. 39 N., R. 11 E.; T. 39 N., R. 12 E.; T. 38 N., R. 12 E.; and T. 37 N., R. 12 E. Likewise, every section lying within the limit of flow in the Luis Maria Baca Grant No. 4 was covered. In the remainder of the area of flow the wells in only the odd-numbered sections were visited.

Method:—The artesian inventory covered an area of approximately 1,430 square miles, as shown by the area of flow (pl. 5) in which it is estimated there are 6,074 flowing wells. The flow for those wells whose discharge was less than 5 gallons a minute was usually estimated. For those wells whose discharge was greater than 5 gallons a minute, the flow was measured either volumetrically or by use of the "jet" method. In the volumetric measurements a stop-watch was used to obtain the time required to fill a container of known volume. In actual practice, 5- and 15-gallon containers were used, the 5-gallon container for the smaller flows and the 15-gallon container for the larger flows. In using the "jet" method, a measurement was made of the inside diameter of the casing, and the vertical

height of the crest of the jet above the top of the casing. The discharge was then computed by using a formula for determining flow from vertical pipes. This formula is written:

$$Q = \frac{[illegible]\, d^2 \sqrt{h}}{\sqrt{[illegible] + 2.627\left(\frac{d}{h}\right)}}$$

Where:

Q = discharge in cubic feet per second.

d = diameter of pipe in feet.

h = height of jet in feet.

This formula was checked many times by volumetric measurements and was found to agree rather closely.

In an artesian inventory of this type it is imperative that no wells that serve to form a basis for the estimate of artesian discharge be omitted, and this is especially true where only the wells in each alternate section are inventoried. Thus, in order to obtain an estimate for any given area, such as a township, it is necessary to double the results of the inventory. Any error, due to omission of wells, would, of course, be doubled in the final estimate. In view of this fact, extreme care was taken to visit and measure every well in the odd-numbered sections.

Equally important, was the necessity of qualifying each measurement of flow in terms of the average annual discharge for each well. It is common practice for a large number of the well owners to allow their wells to flow only during the growing season. For the remainder of the year the wells are plugged, allowing only enough water to escape to prevent the wells from freezing during the winter. Therefore, in addition to measuring the discharge of each well, it was necessary to ascertain the proportion of the year that the well was allowed to flow. This period of restricted flow was usually expressed as a percentage of the year, and the average annual discharge of the well was computed accordingly. Most of the wells, however, are allowed to flow unrestricted throughout the year, and hence no corrections were necessary in computing their average annual discharges.

Most of the wells that supply domestic and stock water on the farms and ranches are restricted in flow throughout the year. Many of the domestic wells are reduced and their water is carried through a pipe line into the houses in such a manner that there is a constant flow through the house at all times. Often these domestic wells are opened for full flow during the summer to irrigate small gardens and lawns. For wells of this type, whose flows were governed by usage, the observer, with the aid of the owner, made the closest possible estimate of the average annual discharge.

A special inventory was made of wells in the largest towns, namely Alamosa, Center, La Jara, Monte Vista, and Sanford, but as there are relatively few wells in Moffat, Hooper, and Mosca, these towns were included in the general inventory.

In Alamosa, the estimate of the total number of wells and their average annual discharge was based on all available information that could be obtained from the records of the city clerk, the water commissioner, the public service company, and Ray Wells, who is the resident well driller. It was estimated that there are approximately 250 private wells within the city limits, and that they have an average discharge of 5 gallons a minute. The municipal water plant furnishes water to about 650 services, but the part of Alamosa lying east of the Rio Grande is dependent wholly upon private wells, as it is outside of the city distribution system. A record of the total quantity of artesian water that was pumped by the municipal water plant in 1936 was obtained from the city water commissioner at Alamosa and is shown in the following table:

TABLE 18.—*Artesian water pumped by the city of Alamosa during 1936*

January	6, 840, 900
February	6, 597, 150
March	7, 607, 700
April	10, 455, 250
May	10, 814, 750
June	12, 220, 600
July	12, 813, 850
August	9, 678, 500
September	9, 704, 800
October	8, 593, 150
November	7, 427, 450
December	7, 692, 500

The total number of 720 wells in Monte Vista and 120 in Center was obtained by actual count. After measuring the discharge of several typical wells in each of these towns, an estimate of 3 gallons a minute was made for the average discharge of all wells in Monte Vista and 5 gallons a minute for all wells in Center. In Center, a municipal plant furnishes water to a part of the town. The flow of the single well which furnishes this supply was measured volumetrically. The city of Monte Vista has no municipal water system, and the inhabitants are dependent wholly upon private wells for their water supply. An estimate of 140 wells in La Jara was made after interviewing residents who are familiar with the distribution of the wells in the town. Several typical wells were measured, and an estimate of 5 gallons a minute for all wells was made. On a similar basis the total number of wells in Sanford was estimated at 150, and the average discharge was estimated at 3 gallons a minute.

The results of the artesian inventory in the five largest towns are shown in the following table:

TABLE 19.—*[illegible] quantity of artesian water used in Alamosa, Center, La Jara, Monte Vista, and Sanford for municipal and domestic supplies during 1936*

[illegible]	[illegible] wells	[illegible] charge of [illegible] (acre-feet)	[illegible]	[illegible]
[illegible]	[illegible]	2,016	338	2,354
[illegible]	120	[illegible]	[illegible]	1,017
[illegible]	[illegible]	1,130		[illegible]
[illegible]	[illegible]	[illegible]		[illegible]
[illegible]		[illegible]		72
Total	1,380	8,323	387	8,710

Table 20 shows by townships the results of the entire artesian well inventory, including the towns.

The flow of the artesian wells in San Luis Valley ranged from only a trickle to about 350 gallons a minute, with an average flow of about 12 gallons a minute. The average flow of the rural wells—that is, excluding those in the five largest towns—is about 14.5 gallons a minute. Table 21 shows by townships the average open flow of the wells. The wells in the five largest towns—Alamosa, Center, La Jara, Monte Vista, and Sanford—are not included, as these wells are not allowed to flow open, but are reduced and the water used for domestic purposes. This table shows in a general way the magnitude of the yield of the wells in different parts of the valley. On the basis of the average yield per well, it is possible to divide the valley into fairly well defined areas of high and low flow. Three localities in particular have appreciably higher flows than the average, namely, (1) the area southwest of Alamosa, in the vicinity of Henry station and westward to the Fountain neighborhood; (2) the area north of the river, several square miles in extent, the center of which is about 6 miles northeast of Alamosa; and (3) an area including the vicinity of Russell Lakes and extending southward to Veteran School. The last mentioned area is noted for its high artesian head and correspondingly large flows.

Several factors are involved in determining the rate of flow of the different artesian wells in the valley. Listed more or less in the order of their importance, these factors are as follows: (1) The thickness and permeability of the water-bearing beds; (2) the altitude of the land surface at each well; (3) the relation of the well to the intake area; (4) the number and distribution of wells tapping the same aquifer; and (5) the construction and development of the wells.

The strong flows of the wells in the vicinity of Russell Lakes are due in part to the preponderance of gravel in the aquifers of this area, almost to the exclusion of the finer sediments, and in part to the nearness of the intake area on the relatively high Rio Grande alluvial fan. The other two areas of high flow that have been described also have a preponderance of coarse material in the aquifers but do not have such high artesian heads.

Although the interior of the valley lies low it is a region of only moderate to weak flows. The absence of strong flows is due in part to the fact that the water-bearing materials in this region consist chiefly of silt and fine sand and that the clay beds are numerous and reach their maximum thickness, and in part to the remoteness of the region from the intake area.

Summary of artesian discharge.—Prior to the present inventory at least three other estimates had been made of the discharge of the artesian wells in the San Luis Valley. In 1891 Professor Carpenter[46] estimated that there were 2,000 artesian wells in the valley, with an assumed average flow of 25 gallons a minute, and he thus computed the total artesian discharge to be about 110 second-feet, which is equivalent to an annual discharge of about 80,000 acre-feet.

[46] Siebenthal, C. E., Geology and water resources of the San Luis Valley, Colo.: U. S. Geol. Survey Water-Supply Paper 240, p. 56, 1910.

TABLE 20.—*Number of artesian wells in the San Luis Valley, Colo., and discharge from them, in acre-feet, during 1936*

	R. 7 E.		R. 8 E.		R. 9 E.		R. 10 E.		R. 11 E.		R. 12 E.		R. 1. W. (Baca Grant)		R. 73 W.		R. 74 W.		R. 75 W.		Total	
	Wells	Discharge	Wells	Discharge	Wells	Discharge	Wells	Discharge	Wells	Discharge	Wells	Discharge	Wells	Discharge	Wells	Discharge	Wells	Discharge	Wells	Discharge	Wells	Discharge
[illegible]							20	270													20	270
[illegible]			44	1,180	110	4,525	78	2,400	2	15											234	8,120
[illegible]	36	2,930	228	16,940	92	[illegible]	46	455	5	115											407	22,175
[illegible]													4	35							4	35
[illegible]													5	75							[illegible]	75
[illegible]	[illegible]	4,210	92	5,380	10	[illegible]	8	75													284	9,745
[illegible]	52	900	[illegible]	6,235	[illegible]	1,290	60	1,290	8	65	1	10									451	9,790
[illegible]	30	[illegible]	[illegible]	6,635	108	2,375	126	620	35	225	12	60									541	9,995
[illegible]	[illegible]	[illegible]	[2] 586	[2] 4,595	82	1,135	92	765	25	150	6	45									973	7,630
[illegible]	[2] 102	[illegible]	[illegible]	[illegible]	78	[illegible]	52	[illegible]	106	2,210	90	2,490									860	12,020
[illegible]	6	10	165	2,790	212	8,105	421	8,775	166	4,140	47	[illegible]									1,022	24,915
[illegible]			12	[illegible]	216	3,865	112	1,510	39	340											[illegible]	5,770
[illegible]					370	4,130	368	2,045	28	[illegible]											[illegible]	7,100
[illegible]					52	185	38	905													90	1,090
[illegible]																	1	30	4	130	8	160
[illegible]															[illegible]	[illegible]					[illegible]	55
Total	582	9,690	[illegible]	48,980	1,384	28,480	1,451	19,885	414	8,185	156	3,400	9	110	[illegible]	55	[illegible]	30	4	[illegible]	[illegible]	118,945

[1] Baca Grant.
[2] Segregation of the wells and discharge by townships in Monte Vista is approximate.

[illegible] *Monte Vista, and Sanford*

	[illegible]	[illegible]	[illegible]	[illegible]	R. 11 E.	R. 12 E.	R. 1 W. Baca Grant	[illegible]	R. 74 W.	[illegible]
[illegible]				[illegible]						
[illegible]		16.6	[illegible]	[illegible]	4.0					
[illegible]		[illegible]	[illegible]	6.1						
[illegible]							5.8			
[illegible]							9.4			
[illegible]	[illegible]	[illegible]	[illegible]	7.8						
[illegible]	[illegible]	21.2	[illegible]	14.3	5.0	7.0				
[illegible]	1.7	20.6	[illegible]	3.2	1.0	3.1				
[illegible]	[illegible]	8.8	8.6	5.2	3.9	4.7				
[illegible]	[illegible]	[illegible]	[illegible]	11.3	[illegible]	17.4				
[illegible]	[illegible]	[illegible]	[illegible]	22.9	[illegible]	11.3				
[illegible]		[illegible]	[illegible]	9.2						
[illegible]			[illegible]	3.8	36.8					
[illegible]			[illegible]	11.7						
[illegible]								[illegible]		
[illegible]									5.0	[illegible]

In 1916 White[47] estimated that there were 5,000 artesian wells in the valley, with an average flow of probably not more than 2 or 3 miner's inches (23 to 35 gallons a minute). His estimate of the total potential discharge of all wells, if allowed to flow unrestricted, was 300 second-feet, or about 219,000 acre-feet a year.

In 1919 Debler[48] estimated that there were 5,850 wells in the valley, and on the basis of measurement of 908 wells, he estimated their average flow at 26 gallons a minute. He estimated the potential annual discharge at 245,000 acre-feet, and considering the wells that were closed during a part of the year, he estimated the actual annual discharge at 187,000 acre-feet.

On the basis of the artesian inventory in 1936, it is estimated that there are 6,074 wells in the valley, with an annual discharge of 118,945 acre-feet. If all wells in the valley were allowed to flow unrestricted, their potential annual discharge would be about 142,000 acre-feet. On the basis of the measurements recorded in table 17, the total discharge of the artesian springs in 1936 is estimated at 47,000 acre-feet. Therefore, the total visible discharge from the artesian wells and springs is estimated at about 166,000 acre-feet of which about 27,400 acre-feet occurs in the springs along or near the upper edge of the confining bed, and hence never enters the main part of the aquifer.

General Conclusions

In the present investigation of the artesian basin the principal objective was to obtain an estimate of the quantity of water discharged by the artesian wells and springs. As a result most of the time was spent in measuring the discharge of the artesian wells and springs, and very little time was allotted to the study of other phases of the artesian system, such as the extent of the recharge area and the amount of recharge.

The quantity of artesian water moving past the boundary of the area of artesian flow (pl. 5), should be equal to the total discharge from the wells and springs in the area of flow, except that it would be less to the extent that artesian water is taken from storage or more to the extent that this storage is increased or there is discharge by upward percolation through the confining beds or underground leakage from the wells. The distance along the boundary of flow is about 180 miles. As indicated on page 256, the average coefficient of transmissibility to a depth of 160 feet, based on the results of tests of the four wells near the boundary of flow, 9K6G1, 12K14R1, 14K25E4, and 15L6K1, is about 7,000. Deducting the average thickness of the shallow valley fill at the wells, which is about 35 feet, the average depth penetrated by the wells below the top of the first confining bed is about 125 feet. The slope of the piezometric surface, as determined from several pairs of wells close to the boundary of flow, ranges from 4 to 13 feet per mile and averages about 9 feet per mile. Using these figures, the quantity of water moving past the boundary of flow in the 125 feet of beds below the top of the first confining bed was computed to be about 12,800 acre-feet a year. The average thickness of the artesian formation below the top of the first confining bed is not known, but the logs of wells close to the boundary of flow indicate it to be at least 500 feet. Thus, to a depth of 500 feet below the top of the first confining bed, the quantity of water passing the boundary of flow would be about four times as much, or about 50,000 acre-feet a year.

According to these computations less than half the total discharge by artesian wells and springs (excluding Diamond and Russell Springs and similar springs which essentially reject water before it enters the artesian aquifer) can be accounted for by the lateral percolation

[47] [illegible]

[48] [illegible] 18, 1919.

from the peripheral intake areas into the area of artesian flow. The figures for the average coefficient of transmissibility or for the hydraulic gradient may be too low, or the total thickness of the artesian beds may be greater than was assumed for the computation. It is possible that the transmissibility of the deeper, untested aquifers is greater than that of those which were tested. Further, it is possible that the average slope of the piezometric surface at the boundary is not truly represented by the heads in the wells that could be measured. The gradient between the trough of the valley and the upper limit of artesian flow on the west slope of Mount Blanca, for instance, is much greater than that assumed in the computations.

PART II

SECTION 3.—GROUND WATER IN THE MIDDLE RIO GRANDE VALLEY, NEW MEXICO[1]

Method of Investigation

Acknowledgments

The work of installing observation wells in the Middle Rio Grande Valley and reading water levels in them was divided areally into three divisions, which corresponded with the three most important operating divisions of the Middle Rio Grande Conservancy District. B. R. Thompson was in charge of the work in the Albuquerque Division, and aided in overseeing the work in the remainder of the area and in the incidental office work. Nestor Lovato was in charge of the work in the Belen Division, which included nearly half the observation wells installed. W. E. Herkenhoff was in charge of the work in the Socorro division. Robert Colvin joined the force in August, was in charge of most of the leveling done, and had much of the responsibility for the preparation of the water-table and depth-to-water maps. Marjorie Allen, besides doing the manifold clerical duties of the Albuquerque office, checked a large part of the field notes and otherwise contributed to the engineering phase of the investigation.

Acknowledgment is gratefully made to many organizations who contributed helpfully to the investigation. The surface water division of the United States Geological Survey and the Bureau of Agricultural Engineering both furnished necessary data. The Middle Rio Grande Conservancy District furnished much information, including levels on several lines of wells in the Belen division. Many bench marks placed on observation wells in the Albuquerque Division by the conservancy district in former years, were still intact and were used in this investigation. Many data, collected in connection with the current Texas-New Mexico suit concerning Rio Grande waters, were kindly furnished by Alan Laflin and Raymond Hill. Special acknowledgment is made of the kindness of Dean W. Bloodgood of the Bureau of Agricultural Engineering, and of Fabian Garcia, director of extension work of the Agricultural and Mechanical College, for access to and permission to use the water level data obtained by Mr. Bloodgood in the period 1918–22.

The aeroplane mosaics obtained by the Soil Conservation Service were placed at the disposal of the investigation and photostatic copies furnished to the Ground Water Division. These were the only accurate maps of the area available and without them no accurate survey of water levels could have been made. These maps, however, were not available until late in the investigation.

The Resettlement Administration kindly furnished records of ground-water levels in their observation wells in the Bosque Farms resettlement project, through G. L. Seligmann, project manager.

The Biological Survey, in course of their investigation of the Bosque del Apache grant as a migratory bird refuge, located and ran levels to the observation wells in the grant. They also furnished a topographic map of the area with a contour interval of 1 foot, which assisted greatly in making the map of the area showing the depth to water.

Scope of Investigation

The shortness of the time available for the present work necessitated that it be of the nature of a survey rather than a thorough investigation. The work involved in covering the entire Middle Valley with observation wells numbering about 900, locating these wells in an unsectionized area for which no accurate detailed maps were available until late in the year, running levels to them, making and recording measurements of water level in them, and cleaning out and deepening them periodically to obtain water samples from them, consumed so much time that little was left for experimental work to clarify important basic problems connected with the source, motion, and disposal of the ground water. The information gathered is to be regarded as base data necessary for a proper ground-water investigation but lacking necessary experimental work to make it complete at present.

The geology and general ground-water conditions of this part of the Rio Grande Valley and tributary area are described concisely by Kirk Bryan in section 1.

Description of Work Done

Area covered.—The Middle Rio Grande Valley extends from White Rock Canyon on the north to San Marcial on the south, a distance of approximately 142 miles. Its average width is about 2 miles. It comprises parts of Sandoval, Bernalillo, Valencia, and

[1] [illegible]

Socorro Counties and within its limits are Bernalillo, the county seat of Sandoval County; Albuquerque, New Mexico's largest city and the county seat of Bernalillo County; Belen, the county seat of Valencia County; and Socorro, the county seat of Socorro County. Within the valley are the pueblos of the Cochiti, Domingo, San Felipe, Santa Ana, Sandia, and Isleta Indians. The territory covered by the ground-water investigation begins at mile post 877 on the Atchison, Topeka & Santa Fe Railway, about 15 miles south of White Rock Canyon, and extends south to mile post 998, about 7 miles north of San Marcial, thus including the Albuquerque and Belen Valleys and most of the Socorro Valley as defined by Bryan in a preceding section of this report.

Nearly all of this area is in the Middle Rio Grande Conservancy District, which is divided into four operating divisions—Cochiti, extending from the head of the valley to Angostura; Albuquerque, from Angostura to Isleta; Belen, from Isleta to San Acacia; and Socorro, from San Acacia to the north line of the Bosque del Apache Grant. Every effort was made to recover the wells previously located by the Conservancy District in order to have a semicontinuous record of depth to ground water in the valley. Because of difficulties in obtaining permission from the Domingo and San Felipe Indians to do work on their reservations in the Cochiti division, this area was omitted from the investigation.

Description of wells.—Most of the observation wells are located along highways, roads, trails, and fences that run laterally across the valley, at or near a fence post, tree, telephone pole, or power pole. To facilitate location, a fence post, tree, telephone pole, or power pole near each well was conspicuously painted. Orange paint was used in the Albuquerque and Belen Divisions, white in the Socorro Division.

The field equipment consisted of a 2-inch post-hole auger, with four 42-inch lengths of ½-inch galvanized iron pipe, threaded on both ends, for extensions. With this equipment a depth of 16 feet could be reached. The wells were as a rule cased with 2-inch galvanized downspout. The casing was inserted to a depth of several feet below the ground-water level to insure ample water for measuring at low stages. The lowest 2 feet of the casing was perforated with slots made with a hack saw in order to facilitate the flow of ground water into the well. The depth to the water level ranged from 1 foot to 16.5 feet. Wells 894.4–1E, 3E, 5E, and 6E penetrated to a depth of about 15 feet below the ground-water level. They consist of a sand-point and ¾-inch galvanized iron pipe, in 42-inch sections, driven into the ground with a sledge.

The original wells placed by the Conservancy District in the Albuquerque and Socorro Divisions were cased with 2-inch boiler tubing to a depth of generally about 2½ feet. This left the lower portion of the well an open hole which in most wells had caved. Wherever necessary, 2-inch galvanized downspout was substituted for this boiler tubing. None of the wells in the Belen Division had been cased, and all were lost by the time this investigation began.

Measurements of depth to the water level were made monthly in 917 wells in the Middle Rio Grande Valley. The work was usually started on the 8th day of the month, and the wells were read in about the same order each month. The measurements were made from the top of the casing. Field work was started in April, but a complete record is not available for either April or May, because the installation of new wells and the recovery of old wells were not completed. Beginning with September, measurements to the water surface were also made in many drains, canals, and laterals.

System of numbering.—The system of line and well designation used in this investigation is based on two important features of the Rio Grande Valley, namely, the Rio Grande and the Atchison, Topeka & Santa Fe Railway. The lines of wells are given numbers corresponding to the numbers that designate the railway mile posts. If the line or its projection begins at some point between mile posts a decimal is added to the mile-post number. The line numbers increase successively southward. In each line the wells are numbered consecutively to the east and to the west of the Rio Grande.

The Albuquerque Division extends from mile post 877, southward to mile post 915, at the Isleta Pueblo. There are 281 wells in this division of which 167 are reclaimed wells of the Middle Rio Grande Conservancy District. The lines of Conservancy wells on the west side of the Rio Grande extended from mile post 912 north to the town of Atrisco, and were numbered consecutively from 1 to 7 in the system of the Conservancy District. On the east side of the Rio Grande the lines of wells extended northward from mile post 912 to the treating plant of the Atchison, Topeka & Santa Fe Railway and were numbered consecutively from 1 to 8. From Mountain Road, in the city of Albuquerque, which is about the center of the Albuquerque Division, the lines extended northward and were numbered from 1 to 18. The original numbering system was retained in the field.

The Belen Division extends from the Isleta Pueblo southward to the San Acacia diversion dam. There are 461 wells in this division. Very few of the original wells of the Conservancy District were located because none of these wells were cased and all the open holes had caved before this investigation was begun. However, the locations of the present wells correspond approximately to the original locations. The original line numbers as well as the original well numbers were

[illegible] in the field. [illegible] were taken from the [illegible] of the survey lines of the drains.

The Socorro Division extends from the San Acacia diversion dam southward to the town of San Marcial. There are 175 wells in this division.

[illegible]—Most of the wells in the Albuquerque and Belen Divisions were located on aeroplane mosaics furnished by the Soil Conservation Service by means of automobile speedometer and pacing from adjacent features shown on the mosaics. In [illegible] fields where it was impossible to use an automobile, and throughout the Socorro Division the wells were located by a transit stadia surevy. The Atchison, Topeka & Santa Fe Railway was used as a base line.

Notes on level net.—In the Albuquerque Division most of the old Conservancy District benchmarks near wells were found. These consisted either of wooden stakes driven to ground level or no. 60 spikes driven into fence posts, trees, or poles nearby. Most of these altitudes were assumed to be correct, and altitudes on neighboring observation wells at which benchmarks were not found were established by leveling from these points. In general, therefore, the altitudes correspond to the Conservancy District datum. This datum is apparently somewhat at variance with the newer levels established by the United States Coast and Geodetic Survey. Because time was not available for running a complete new system of levels, the old datum was used except for lines 877, 884, 911.8, 908.1, where, in the absence of any altitudes set by the Conservancy District, the Coast and Geodetic Survey datum was used, and line 892.5, where there appeared to be an error of 0.36 foot on the east side of the river and 0.75 foot on the west side, and on line 896.3 where there was an error of from 0.35 to 0.67 foot. From line 877.0 to line 889.6 it appears that the Conservancy datum is from 0.42 to 0.60 foot lower than the Coast and Geodetic Survey datum. From line 890.8 to line 901.5 the Conservancy datum appears to be from [illegible] foot higher than the United States Coast and Geodetic Survey datum. On lines of wells on the west side of the Rio Grande from mile post [illegible] to mile post [illegible] the Conservancy datum appears to be from 0.08 to 0.38 foot below the Coast and Geodetic Survey datum. On the east side of the river from [illegible] to mile post [illegible] the Conservancy datum appears to be from 0.17 to 0.33 foot higher than the Coast and Geodetic Survey datum with the exception of [illegible], which are [illegible] and [illegible] foot, respectively, above the United States Coast and Geodetic Survey datum.

In the Belen Division new lines of levels were run from benchmarks established by the Conservancy District. Altitudes were not obtained on all lines. Altitudes on well lines 920.1, 921.1, 921.4, 921.8, 922.9, 923.7, 924.1, 925.3, 928.8, 929.5, 930.3, 931.6, 932.4, 934.2, 936.4, 936.9, 938.6, and 939.6 were established by the Middle Rio Grande Conservancy District in 1936. The remainder were run by the Division of Ground Water of the Geological Survey.

In the Socorro Division all levels were run during the present investigation by the Geological Survey, using benchmarks established by the Conservancy District.

The Water Table

Form and Altitude

Plates 6-9 (map vol.) show the form and altitude of the water table in the irrigated area of the Middle Rio Grande Valley by means of contours at intervals of 1 foot. The control points are the water levels in most of the wells shown and at drains where marked by small arrows. The water levels in the canals are not controlling altitudes, because in general the water table lies considerably below the canals. Seepage from canals, however, raises the water table under them.

The water levels read during October 1936 were used in drawing the contours of the water table and the lines showing the depths to the water table. The shortness of the period of observation makes it inadvisable to use any system of means, as the mean based upon the observations now available would unduly emphasize summer conditions. The indications of the present data are that the water table during the month of October was at approximately its mean position for the year, being somewhat lower than its midsummer position in irrigated areas and somewhat higher than its midsummer position in unirrigated areas, where there was heavy use of water by native vegetation.

The significance of the form of the water table and of its fluctuation is discussed in succeeding parts of this paper.

Depth to Water

[illegible]—Plates 6-9 (map vol.) show the depth to water during the month of October 1936 in nearly all parts of the Middle Rio Grande Conservancy District. A heavy line represents a depth to water of 8 feet along the outer edge of the valley. In areas outside this line the depth to water is greater than 8 feet. This line generally, but not invariably, follows the bluffs or hill slopes. A similar heavy line shows

areas within the valley in which the depth to water is greater than 8 feet. Such areas are marked 8+. A line of medium weight represents a depth to water of 6 feet. In areas shown between this line and the heavy 8-foot line, the depth to water is between 6 and 8 feet, and the areas are marked 6—8. Light lines mark the 4-, 3-, 2-, 1-, and 0-foot limits. The areas between the 4- and 6-foot lines are marked 4—6. Areas in which the water table is within 4 feet of the surface are cross-ruled and the density of ruling increases with the shallowness of the water table, except that to prevent confusion, areas of surface water are unruled and are designated by the letter S.

The map is based on depths to the water levels in the observation wells in October 1936. Previous determinations of depths to water have been based on mean depths through the year, and it would therefore have been desirable to show mean depths on this map. In the absence of records for a complete year, the data for October were chosen as being probably nearer the annual mean than those of any other month, because in irrigated areas the depth to water is generally less in the summer than in October, whereas in unirrigated areas of natural vegetation it is generally greater. Tables 1 and 2 give the average depth to water and the change in water level from July to October in each subdivision of the valley.

Method of constructing maps.—The ideal method of constructing a map showing depth to water consists in comparing a topographic map of small contour interval with a map of the water table of the same contour interval and referred to the same datum. The construction of a map showing depth to water by this method is a more or less mechanical process of connecting the points of intersection of the two sets of contours. This process reduces the human element to a minimum and insures that topographic irregularities are taken into account.

In the absence of detailed contour maps, the measurements of depth to water may be plotted and the lines showing depth to water may be drawn accordingly. Such a process does not take into account the topographic irregularities between points of observation. If the area is only very gently rolling, as the Rio Grande flood plain, the errors made will presumably balance one another, but local accuracy cannot be attained.

The depth-to-water map of the Bosque del Apache Grant was made by the first method. A topographic map [2] of this area with a 1-foot contour interval was kindly furnished by the United States Biological Survey, and elevations on the observation wells in the grant were determined by the Biological Survey in the course of the mapping. Strict comparability of the topography and the water-table map was therefore assured. The greater amount of detail in this map as compared with the maps of other parts of the valley is at once apparent.

For the remainder of the valley the only topographic maps available were those of the Middle Rio Grande Conservancy District revised from the map prepared by the State engineer of New Mexico in 1918. These maps could not be used for direct comparison with the water-table map. In several places, especially in the Socorro Division, there had been considerable topographic change by floods, principally that of 1929. In the remainder of the area there were so many discrepancies in altitudes as determined in this survey and as shown on the map, that it seemed better to draw the lines showing depth to water directly. In the Middle Rio Grande Conservancy District, therefore, the depths to ground water as determined in the field were plotted on the map. Preliminary lines showing depths to water were drawn on the basis of these data. These lines were then adjusted to conform to relief features shown on the airplane maps of the valley and to the major topographic trends shown on the topographic maps of the Conservancy District.

The resulting map is not accurate in detail. There may be some question as to whether the mapping of depths to water in as much detail as is shown is justified by the data available, either as to depths to water or, more particularly, as to topography. However, the individual errors in mapping should more or less balance each other and the total acreage with specified depths to water in the different localities should be approximately as indicated, and should form a reliable basis for estimating the amount of lowering of the water table effected by the construction of the drains.

Average depths to water and changes in depth since 1927.—Table 1 (p. 274) gives the acreage in each part of the Middle Rio Grande Valley with ground water at different specified depths in October 1936. These acreages were determined by measuring the areas on the depth-to-water map by means of a planimeter. The areas are also expressed in percent of the total area surveyed.

Table 2 (p. 274) gives data on the depth to ground water in the different areas in the Middle Rio Grande Valley at the present time and for the period before drainage was begun. The latter data are taken from the official plan [3] of the Conservancy District and represent average conditions during a full year in 1926

[2] [illegible] feet; contour interval 1 foot; U. S. Bur. Agr. Eng., 1936.

[3] [illegible]

[illegible] and 1927. The data are presented in each case as the fraction of the total area surveyed having ground water over specified depths.

The areas compared are not exactly coextensive because of the indefinite nature of some of them. The areas considered in the present survey are as follows:

1. Algodones-Bernalillo.—Valley land on east side of river [illegible] of T. 14 N., on the east by the fourth section line east of east boundary of R. 3 E., on south by first section line north of north boundary of T. 11 N.

2. Coralles.—Valley land on west side of river throughout [illegible]

3. Alameda-Albuquerque.—Valley land east of river abutting the Algedones-Bernalillo area and bounded on the south by an arbitrary line 3,000 feet north of north boundary of T. 9 N.

4. Atrisco-Pajarito-Isleta.—Valley land west of river from head of Arenal main canal to an east-west line drawn from west [illegible]

5. Barr.—Valley land east of river abutting the Alameda-Albuquerque area on north; bounded on south by an arbitrary line bearing N. 74° E. from the mouth of the Barr riverside drain.

6. Peralta-Tome.—Valley land east of river from Isleta to bridge over Rio Grande at Belen.

7. Los Lunas-Belen.—Valley land west of river bounded on north by east-west line drawn from west end of Isleta Bridge and on south by south boundary of T. 4 N.

8. San Juan.—Valley land east of river extending from head of San Juan Canal south to La Joya Acequia where it approaches the river in sec. 28, T. 2 N., R. 1 E.

9. San Francisco.—Valley land west of river abutting Los Lunas-Belen area on north, bounded on south by Rio Puerco.

10. San Acacia, Lemitar, Socorro.—Valley land west of river bounded on north by San Acacia acequia, on south by south boundary of the Town of Socorro Grant.

11. San Antonio.—Valley land west of river bounded on north by south line of the Town of Socorro Grant, on south by the north boundary of the Bosque del Apache Grant.

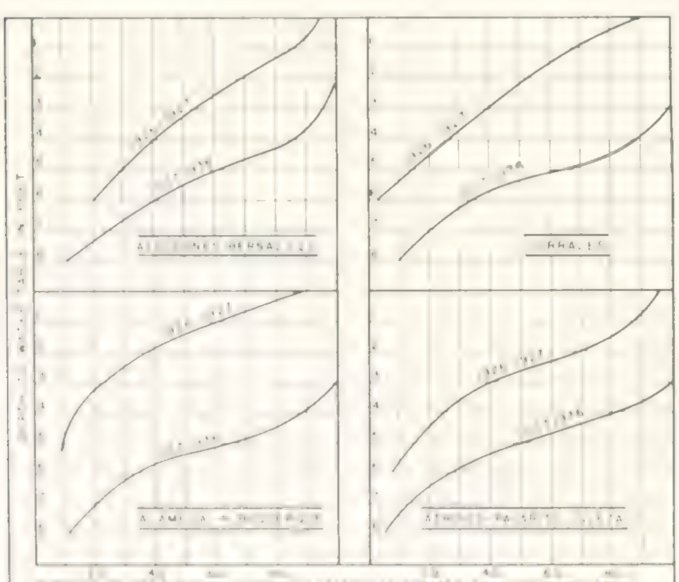
12. Bosque del Apache.—Valley land west of river included in the Bosque del Apache Grant.

The computations of average depth are made in each case by assuming the average depth for each classification to be the intermediate value between the limits for that classification; for instance, the average depth for the area with depth to ground water between 0 and 1 foot is taken as 0.5 foot, and for that between 1 and 2 feet as 1.5 feet. These data are presented graphically in figures 57–60.

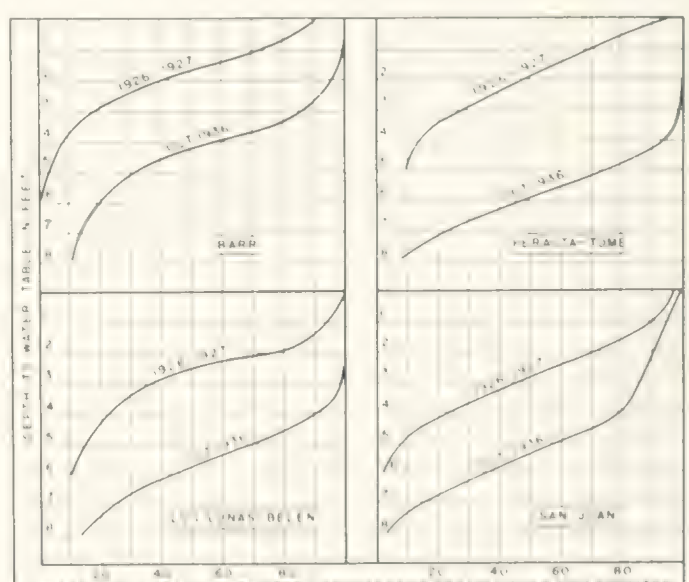
The best-drained areas are indicated to be the Peralta-Tome area, the Socorro division, and the Corrales area. The 1926–27 and 1936 percentages for the Bosque del Apache tract are in close agreement. The slight over-all lowering of the water table indicated in this tract is in part due to the slight amount of drainage caused by the extension of the San Antonio riverside drain into the area. This agreement seems to indicate that probably the figures for the other districts are properly comparable.

Fluctuations of the Water Table

Seasonal fluctuations.—The present investigation has not covered enough time to determine the normal seasonal fluctuations of the water table. It has shown, as might be expected, that the seasonal fluctuations in irrigated and unirrigated areas are opposite in trend. The irrigated areas receive water in the growing season in excess of their demand and consequently the water



[illegible]



[illegible]

table rises in summer. In the unirrigated areas the vegetation draws heavily in summer on the ground water, and hence in these areas the water table falls in summer. After the growing season the water table generally falls in the irrigated areas and rises in the unirrigated areas.

These typical changes are shown by the average fluctuations in the several divisions of the valley between July and October 1936, given in table 2, page 274. The Bosque del Apache Grant is unirrigated except by overflow from the Socorro main canal at its north border. Between July and October the water table showed a net average rise of 0.86 foot, and it continued to rise in the ensuing months. There are no areas in which all the land is irrigated and hence the declines of the water table given in table 2, are not entirely representative of the change in irrigated areas. However, the more heavily irrigated areas show the greater decline. The wells on line 900.4, just north of Albuquerque, show the typical fluctuations of the water table in a heavily irrigated area. The water levels in these wells reached maximums in June and July, then fell an average of 1.08 feet by October, and declined 0.64 foot more by January.

Diurnal fluctuations.—Description of areas where diurnal fluctuations were observed.—Studies of the diurnal fluctuations of the water table were made in two areas of native vegetation south of Socorro. These studies were made by means of automatic water-stage recorders located on wells 980.4–4W and 993.1–6W. The recorders were furnished for this purpose by the Bureau of Agricultural Engineering.

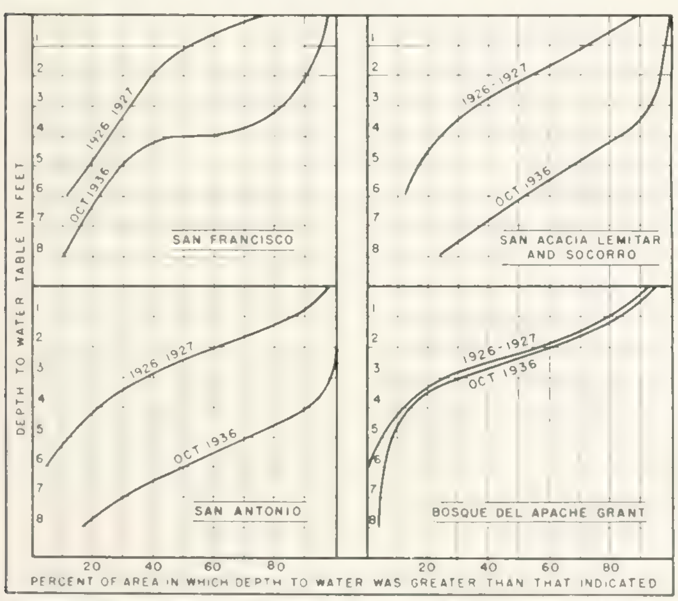


FIGURE 59.—Depth to water in parts of the Belen and Socorro Divisions in 1926-27 and in 1936

Well 980.4–4W, which has the longest record, was a dug well with the water table about 4 feet below the land surface. It was located in a grove of small cottonwood trees, with sparse salt grass between the trees, about 1,800 feet west of the Socorro Riverside drain. When the recorder was installed on June 1, 1936, the depth to water was 3.98 feet. The water level in the well sank rather uniformly, except for diurnal fluctuations, until August 3 when it had reached a depth of 5.32 feet. It remained about constant at this level until August 20, when coincident with a rain it rose somewhat. It maintained a depth of more than 5 feet until September 11, when on the occasion of another shower the water table began to rise. On September 27 snow fell in the area. Thereafter the diurnal fluctuations were small and the water table rose steadily but at a constantly diminishing rate to a depth of 2.80 feet on January 1, 1937.

In order to relate the fluctuations observed at the recorder well to fluctuations elsewhere in the immediate neighborhood, and in different types of vegetation, satellite wells were placed in critical localities. Well 980.4–3W was a sandpoint driven about 10 feet below the water table close to the recorder well. Well 980.4–2W was about 525 feet east of the recorder in small cottonwoods. Well 890.4–1W was about 1,100 feet east of the recorder and about 700 feet west of the riverside drain in a grove of large cottonwoods. Well 980.4–5W was 250 feet west of the recorder in sparse salt grass.

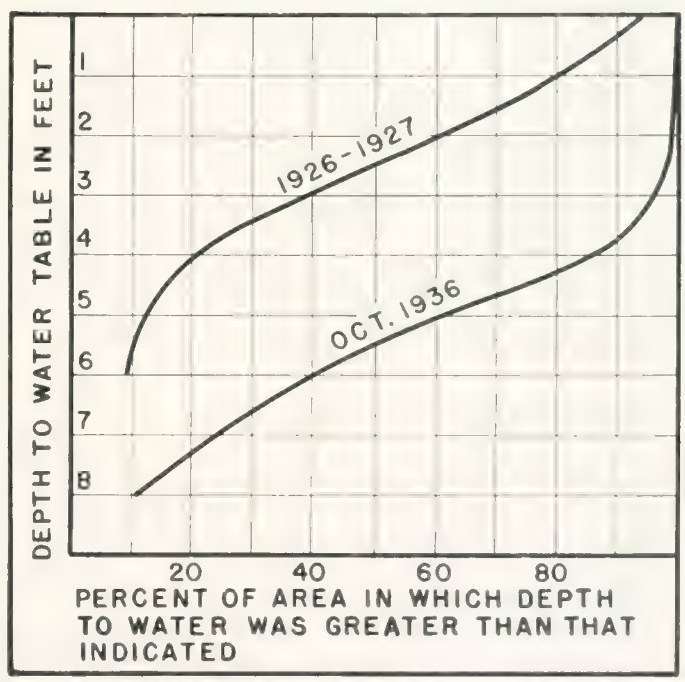


FIGURE 60.—Depth to water in Middle Rio Grande Conservancy District in 1926-27 and in 1936

TABLE 1.—*Areas in Middle Rio Grande Valley having ground water at given depths in October, 1936*

[illegible]		[illegible]	[illegible]	[illegible]	2-3 feet	[illegible]	4-6 feet	[illegible]	Over 8 feet	Total area surveyed	Area not surveyed	Total val- [illegible]
[illegible]	[illegible]	-	[illegible]	[illegible]	[illegible]	[illegible]	3,385.00	1,915.00	777.00	[illegible]		7,043.00
	[illegible]	-	[illegible]	[illegible]	4.21	[illegible]	48.16	27.23	11.10	[illegible]		
[illegible]	[illegible]	-	[illegible]	[illegible]	0	[illegible]	1,722.00	688.00	355.00	[illegible]	631.00	3,748.00
	[illegible]	-	[illegible]	[illegible]	0	11.28	55.24	[illegible]	11.38	100.00	[illegible]	
[illegible]	[illegible]	-	0	31.00	597.00	2,072.00	6,535.00	2,901.00	1,853.00	[illegible]	1,468.00	15,457.00
	[illegible]			.22	[illegible]	14.80	46.70	20.73	13.28	100.00	10.48	
[illegible]	[illegible]			[illegible]	11.00	1,832.00	7,025.00	2,850.00	528.00	12,246.00	1,887.00	14,133.00
	[illegible]			0	[illegible]	14.96	[illegible]	23.27	4.31	100.00	15.41	
[illegible]	[illegible]		13.00	178.00	408.00	1,322.00	1,730.00	102.00	490.00	4,543.00	0	4,543.00
	[illegible]	-	.28	3.90	9.00	29.10	38.10	8.85	10.77	100.00	0	
[illegible]	[illegible]	-	0	0	92.00	933.00	9,775.00	7,760.00	1,490.00	20,050.00	0	20,050.00
	[illegible]	-	0	0	[illegible]	4.66	[illegible]	38.70	7.43	100.00	0	
[illegible]	[illegible]	-	0	64.00	236.00	1,960.00	11,215.00	[illegible]	3,120.00	23,820.00	674.00	24,494.00
	[illegible]	0	[illegible]	.27	.99	8.24	47.10	30.30	13.10	100.00	2.82	
[illegible]	...acres	69.00	363.00	[illegible]	376.00	583.00	3,815.00	[illegible]	224.00	[illegible]		8,499.00
	[illegible]	[illegible]	4.27	4.98	4.43	6.86	44.88	31.15	2.62	100.00	0	
[illegible]	acres	[illegible]	[illegible]	235.00	408.00	1,843.00	1,437.00	580.00	554.00	5,344.00	0	[illegible]
	percent[1]	2.88	[illegible]	4.40	7.64	34.48	26.87	10.87	10.37	100.00	0	
San Acacia, Lemitar, Socorro	acres	0	182.00	186.00	322.00	1,107.00	3,395.00	2,928.00	2,516.00	10,636.00	0	10,636.00
	[illegible]		1.71	1.75	3.02	10.40	31.85	27.62	23.65	100.00	0	
San Antonio	[illegible]	0	0	0	91.00	415.00	2,520.00	[illegible]	923.00	6,036.00	0	[illegible]
	[illegible]	0	[illegible]	0	1.51	[illegible]	41.75	34.56	15.30	100.00	0	
[illegible]	[illegible]	358.00	814.00	1,772.00	2,040.00	1,476.00	544.00	230.00	208.00	7,442.00	448.00	[illegible]
	[illegible]	4.81	[illegible]	[illegible]	27.42	[illegible]	7.32	3.09	2.80	100.00	[illegible]	
[illegible]	[illegible]	223.00	712.00	1,130.00	[illegible]	[illegible]	[illegible]	31,981.00	12,830.00	115,323.00	4,660.00	119,983.00
	[illegible]	.19	[illegible]	.98	[illegible]	[illegible]	45.64	27.69	11.12	[illegible]	[illegible]	

[1] [illegible]

TABLE 2.—*Comparison of depths to ground water in Middle Rio Grande Valley in 1926–27 and in 1936*

[illegible]		[illegible] area with depth to ground water [illegible]							Above surface	Unsur- [illegible] percent [illegible]	[illegible] depth to [illegible] (feet)	Average lowering [illegible] table (feet)	Average change [illegible] to Octo- [illegible] (feet)	Total area in each [illegible]	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]						[illegible]	Unsur- veyed (acres)
[illegible]	1926-27		20.97	39.71		70.21	86.49	95.23	4.77	1.72	3.58			11,983	197
	1936	11.10	38.33	86.49	[illegible]	99.54	99.71	100.00		[illegible]	5.72	[illegible]	−0.33	7,043	0
[illegible]	1926-27		2.86	[illegible]	[illegible]	51.71	69.52	91.64	8.36	[illegible]	2.48			3,038	0
	[illegible]	11.38	33.48	88.72	[illegible]					20.25	5.73	3.25	−.30	3,117	631
[illegible]	[illegible]		8.02	[illegible]	[illegible]	[illegible]	[illegible]	88.48	11.52	0	1.99			14,675	[illegible]
	[illegible]	13.28	34.01	[illegible]	[illegible]	99.78	100.00			10.48	5.61	2.62	−.68	13,989	1,468
[illegible]	1926-27		7.22	[illegible]	[illegible]	72.60	89.25	96.87	3.13	1.17	3.09			15,823	186
	1936	4.31	27.58	84.94	[illegible]	100.00				15.41	5.41	2.32	−.86	12,246	1,887
Barr	[illegible]		[illegible]	7.60	....	41.05	72.59	91.18	8.82	[illegible]	1.91			4,185	0
	[illegible]	10.77	[illegible]	57.72	86.82	95.82	99.72	[illegible]		[illegible]	4.80	[illegible]	−1.62	4,543	[illegible]
[illegible]	[illegible]		9.33	13.56		47.99	[illegible]	93.24	6.76	[illegible]	2.32			[illegible]	[illegible]
	1936	7.43	46.13	[illegible]	[illegible]	100.00				0	5.99	[illegible]	[illegible]	20,050	[illegible]
[illegible]	1926-27		[illegible]	22.39		75.39	[illegible]	99.88	.12	.37	3.23			25,017	92
	[illegible]	13.10	43.40	90.50	[illegible]	99.73	100.00			2.82	[illegible]	[illegible]	−.40	23,820	674
[illegible]	[illegible]		1.51	[illegible]		68.22	91.34	[illegible]	3.03	.39	2.87			[illegible]	[illegible]
	[illegible]	[illegible]	33.77	78.65	[illegible]	89.94	94.92	99.19	.81	[illegible]	5.10	2.23	[illegible]	8,499	0
[illegible]	[illegible]		11.52	[illegible]	....	39.26	[illegible]	75.48	24.52	[illegible]	[illegible]			4,616	0
	1936.	[illegible]	21.24	18.11	82.59	90.23	94.63	97.12	2.88	0	4.50	2.38	+1.39	5,344	[illegible]
[illegible]	1926-27..		12.47	24.36		53.55	72.79	88.78	11.22	4.76	[illegible]			13,437	[illegible]
	1936..	[illegible]	51.27	83.12	[illegible]	[illegible]	98.29	100.00		[illegible]	6.13	3.47	+.22	10,636	0
[illegible]	[illegible]		4.81	21.63		63.31	87.10	97.65	2.35	37.31	2.83			5,016	2,620
	1936	15.30	[illegible]	91.61	[illegible]	100.00				0	6.16	3.33	−.07	6,036	0
[illegible]	1926-27.		0	11.55		60.04	80.12	93.07	6.93	[illegible]	2.37			6,290	1,985
	1936	2.80	[illegible]	13.21	[illegible]	[illegible]	84.26	95.19	4.81	6.02	2.60	[illegible]	[illegible]	7,442	448
[illegible]	1926-27..		[illegible]	21.69		59.32	79.56	[illegible]	6.15	[illegible]	2.75			121,559	3,761
	1936	11.12	38.81	[illegible]	[illegible]	98.21	99.19	99.81	.19	4.04	[illegible]	[illegible]	[illegible]	115,323	[illegible]

NOTE.—Bosque del Apache area not included in total. [illegible] 1936 are from measurements taken in October; those for the earlier period are averages for 12 consecutive months in 1926 and 1927.

Well 980.4-6W was 1,250 feet west of the recorder in salt grass, and about 800 feet east of the Luis Lopez drain A. Well 980.3-1W was in a willow thicket 600 feet [illegible] of the recorder. Well 980.5-1W was in a tornillo thicket 500 feet south of the recorder. The depth to water was about 5 feet in all these wells in [illegible] except in 980.4-1W, in which it was about 4 feet. All showed about the same seasonal fluctuation as did the recorder well.

The second recorder was placed over well 993.1-6W, a dug well in a salt-grass meadow about 2 miles north of Elmendorf. The depth to water ranged from 1.8 feet in July to about 0.4 foot when last read in November.

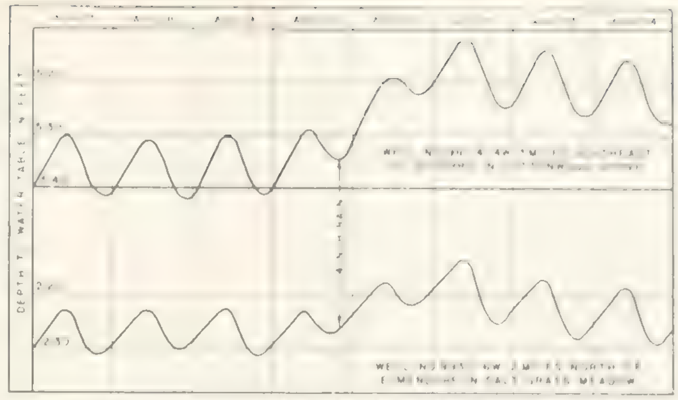
Character of Diurnal Fluctuations.—Figure 61 shows the diurnal fluctuations of the water table in the two wells equipped with recorders for the week of August 17 to 24, 1936. The fluctuations shown are typical

of the fluctuations during the growing season. The water table fluctuated during the course of a day about 0.1 foot at well 980.4-4W, in the cottonwood grove, and slightly over half this amount at well 993.1-6W, in the salt-grass meadow. The recovery of the water table under the cottonwoods generally began several hours after sundown, whereas under the salt grass it began to recover very shortly after sundown. The lag shown by the cottonwoods may be due to different soil conditions, but seems most likely to result from the greater storage of sap in the trees. Presumably a large quantity of water is stored normally in the tree and this furnishes water for transpiration during the early part of the morning. After the tree has ceased transpiring in the evening there is apparently a continued draft on the ground water for some time in order to replenish the sap in the tree.

On August 20, light showers fell at both recorders, amounting to 0.14 inch at Socorro. There was an immediate rise of the water table presumably due to reduction in transpiration by the vegetation and substitution of soil moisture derived from the rainfall for that from capillary rise of ground water. The water table after rising a little for 2 days resumed its downward trend.

Significance of Diurnal Fluctuations.—The typical graph of the daily fluctuation of a shallow water table in an area overgrown by unirrigated vegetation is a more or less symmetrical curve, falling in the daytime when the vegetation is transpiring water and rising in the night when the vegetation is dormant. The correlation with use by the vegetation is obvious. The vegetation in the daytime uses water in excess of the rate at which it can be delivered to the area by ground-water flow, and consequently the water table lowers; at night the delivery by ground-water flow exceeds the rate of use, and consequently the storage in the area increases and the water table rises. Accompanying the diurnal fluctuations during the growing season there is usually a residual fall of the water table, and there is usually a rise during the nongrowing season. The amount of the residual fall is limited, however, within a narrow range by the root zone of the plants; if the water table should fall below the reach of the roots transpiration would cease and the water table would no longer decline. Thus the amount of daily fluctuation is an index of the use of water by the vegetation.

White[4] has made a quantitative application of this principle to determine the use of water by native vegetation in the Escalante Valley, Utah. At night, when the vegetation is dormant, there is presumably no



[illegible]

loss of water from the area, and the rate of rise of the water table measures the input of ground water into the area. If this rate is projected through the entire 24 hours it represents what would be the rise of the water table if there were no use of water. If this virtual rise of the water table is corrected for the residual rise or fall during the day and multiplied by the factor expressing the quantity of water equivalent to a given change in the water table, which White calls the specific yield, the use of water by the plant for that day will be determined. White[5] expresses the relationship by the formula q equals $y(24r \pm s)$, in which q is the depth of water withdrawn, y is the "specific yield" of the soil in the belt of fluctuation of the water table, r is the hourly rate of rise of the water table during the period of full recovery, generally from midnight to 4 a. m., and s is the net fall or rise of the water table during the 24-hour period. The quantity $(24r \pm s)$ may be called the "virtual fall" of the water table, and represents the theoretical amount the water table would fall, if there were no recharge to the area and the vegetation could nevertheless continue to extract water, the factor y being considered constant. The "virtual fall" of the water table at the two recorder wells is given by months in the following table.

The quantity $(24r \pm s)$, in feet, as determined in two localities of native vegetation, by months:

	Well [illegible]	Well 993.1-6W
June	9. 57	-
July	9. 52	6. 69
August	9. 00	[illegible]
September	4. 57	3. 49
October	. 76	1. 66

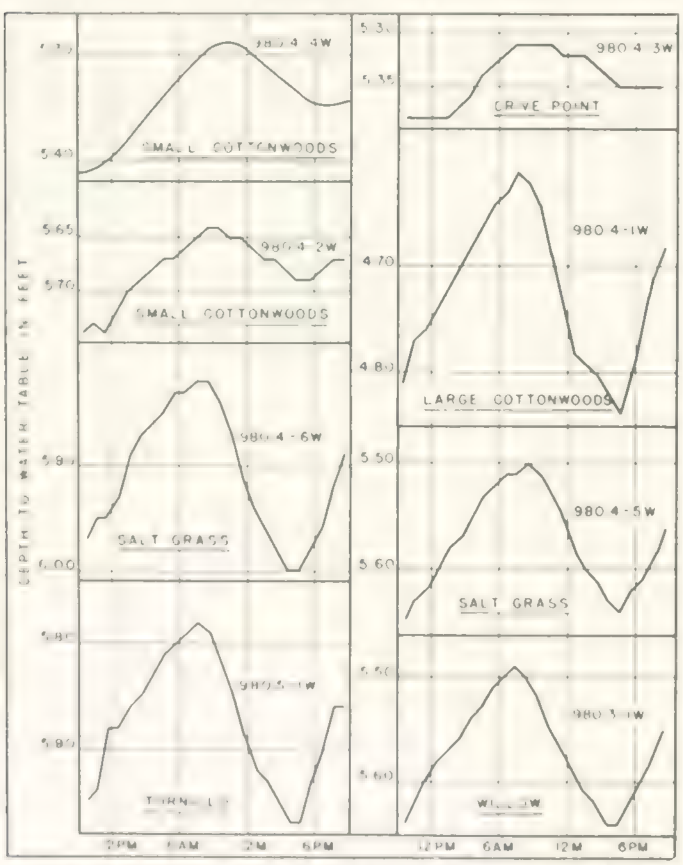
The quantities given are of course not the actual water use. They are indexes to the water use, the relationship between the index and the actual use of water being given by the quantity y. The use of water by months

[4] White, W. N., A method of estimating ground-water supplies based on discharge by plants and evaporation from soil, U. S. Geol. Survey Water-Supply Paper 659, pp. 1-105, 1932.

[5] [illegible]

is probably in the same ratio as that between the specific yields.

Water levels in the satellite wells around well 980.4–4W were read at approximately hourly intervals from 9 a. m. on August 19 to 9 p. m. on August 20, in order to compare diurnal fluctuations in the surrounding territory with that given by the recorder. These records are given graphically in figure 62. All the surrounding wells showed greater fluctuations of water level than the recorder well, excepting wells 980.4–2W and 980.4–3W. The fluctuation in small cottonwoods was about the same as that in the recorder well. In well 980.4–3W, a drive point going about 10 feet below the water table and as close as possible to the recorder well, the water rose and fell about as it did in the recorder well, but it neither rose as high nor fell as low. The ratios of the fall in water level during the day in each of the satellite wells to the fall in the recorder well were as follows: 980.4–3W (drive point near the recorder) 0.7; 980.4–2W (small cottonwoods) 0.8; 980.4–1W (large cottonwoods) 3.8; 980.4–5W (sparse salt grass) 2.3; 980.4–6W (salt grass) 3.0; 980.3–1W (willows) 2.5; and 980.5–1W (tornillo) 3.2. The complete significance of these ratios is in doubt. In part, they represent different rates of transpiration and different rates of draft on ground water. It is probably significant that the fluctuation in wells 980.4–2W and 980.4–4W, both in groves of small cottonwoods, was about the same, while that in well 980.4–1W, in a grove of large cottonwoods, was much greater. However, because the amount of fluctuation is also dependent on the character of the soil in which the water table fluctuates, it is evident that these ratios are not necessarily the ratios of uses of water by the different types of vegetation.



[illegible]

Insufficiency of Data for Determining Consumptive Use.—White's study of the relationship between diurnal fluctuations of the water table and use of water by native vegetation in the Escalante Valley was accompanied by intensive study by means of tanks to determine the proper value of "specific yield" to be applied for each soil used. The application of this method of study of consumptive use by natural vegetation produced in his area results closely comparable to results obtained from studies with soil tanks.

The theory appears to be sound but the use of the term "specific yield" is probably unfortunate as implying that the factor y in the formula is the same specific yield factor that is used in other types of investigation. Meinzer [6] has defined specific yield as the ratio of (1) the volume of water which, after being saturated, a soil will yield by gravity, to (2) its own volume. It is implied that the time of draining is unlimited. This is obviously a different amount than would drain in the approximately 12-hour period involved in diurnal fluctuation. A better term would probably be the more general though closely related term "effective porosity", which is defined as the ratio of (1) the volume of water (or other liquid) which after being saturated a soil will yield, under any specified hydraulic conditions, to (2) its own volume.[7] If the factor y is regarded as the effective porosity of the soil, the specific conditions being identical with those involved in the fluctuations in a given locality, the formula appears to be theoretically correct. In order, therefore, to compute by means of water-table fluctuations the use of water by vegetation it is necessary to know the effective porosity specific to the hydrologic condition involved. This factor can probably only be ascertained with exactness by laboratory experiments duplicating the fluctuations in a column of the natural soil. Such methods were used by White in the Escalante Valley. In the present investigation time and personnel were not available for

[illegible]

similar experiments. It may be of some value, however, to examine certain available data regarding the soil columns near the recorders.

At the time the hourly readings of water levels in the satellite wells near well 980.4–4W were made, on August 19 and 20, soil samples were taken near both recorders by the Bureau of Agricultural Engineering. Two sets of samples were taken at each recorder, one in the evening of August 19 and the other in the morning of August 20, in the hope that by making soil moisture determinations at high and low stages of the water table, differences in the total soil moisture in the capillary fringe would be noted that could be correlated with the fluctuations of the water table. However, the soil apparently varied so much within the few feet between successive sampling points that no significant differences could be found.

The characteristics of the soil columns near the two recorder wells as determined by the Bureau of Agricultural Engineering are given in tables 3 and 4. The volume weight is the apparent specific gravity of the soil.

It is evident that consumption of water computed from the water-table fluctuations and using the values of pore space minus moisture equivalent by volume as the effective porosity would be exorbitant. Thus the computed values would be about 11 feet at well 980.4–4W for the period June 1 to December 31 and about 3.80 feet at well 993.1–6W for July 1 to October 31. It is evident that the effective porosity pertaining to these fluctuations is much smaller. In well 993.1–6W the capillary fringe evidently reaches the surface, as the topsoil is quite moist. The pertinent effective porosity must be accordingly reduced. In well 980.4–4W, possible causes for low effective porosity are more difficult to find. It may be that the abrupt change in moisture content at 3 feet noted in both sets of samples, represents a bed of coarser material overlying finer, so that, in this well also, the capillary fringe is definitely broken at this fixed level and is thus prevented from fluctuating with the water table.

Movement of Ground Water

General Principles of Ground-Water Movement

So far as can be learned from experiments approximating the conditions of nature, ground water always moves in conformity with Darcy's law, which states that the rate of flow is equal to a factor expressing the ease of movement through the containing medium multiplied by the pressure gradient under which the water moves. The factor expressing the ease of movement through the containing medium has been evaluated in many ways according to the type of work to which it is desired to apply the factor. That which will be used in this report is the coefficient of permeability defined by Meinzer[8] which expresses this ease of movement as the number of gallons of water at a temperature of 60° F. which will move in 1 day through a cross section of the water-bearing material 1 foot square under a pressure gradient of 1 foot in 1 foot. The ease of movement in an aquifer, as a whole, can under certain conditions be determined

TABLE 3.—[illegible] Socorro

SAMPLES TAKEN [illegible]

[illegible]	[illegible]	[illegible]	[illegible]	Moisture equivalent, in percent	[illegible]
[illegible]	[illegible]	[illegible]	1.08	18.1	11.6
0.5–1.0	[illegible]		[illegible]	[illegible]	
1.0–1.5	4.3	49.8	1.33	2.2	1.8
1.5–2.0	3.2		1.33	[illegible]	
2.0–2.5	4.1	[illegible]	[illegible]	1.4	1.4
2.5–3.0	[illegible]		[illegible]	1.3	
3.0–3.5	[illegible]	48.1	[illegible]	2.9	2.4
3.5–4.0	16.1		[illegible]	1.9	
4.0–4.5	[illegible]	[illegible]	1.70	1.8	2.2
4.5–5.0	21.4		1.70	2.5	
5.0–5.5	24.7	41.2	1.57	2.5	2.5
5.5–6.0	[illegible]		1.57	2.5	

SAMPLES TAKEN AT 10.15 A. M. AUG. 20, 1936

0–0.5	15.2	47.9	1.38	19.5	11.7
0.5–1.0	[illegible]		1.38	3.9	
1.0–1.5	3.2	[illegible]	1.56	2.1	[illegible]
1.5–2.0	2.5		1.56	1.8	
2.0–2.5	[illegible]	42.0	1.53	2.0	[illegible]
2.5–3.0	[illegible]		1.53	2.2	
3.0–3.5	12.2	23.0	2.04	2.7	2.7
3.5–4.0	[illegible]		2.04	2.8	
4.0–4.5	[illegible]	[illegible]	1.56	3.3	3.5
4.5–5.0	[illegible]		1.56	[illegible]	
5.0–5.5	[illegible]	[illegible]	1.88	[illegible]	[illegible]
[illegible]	[illegible]		1.88	[illegible]	

TABLE 4.—*Soil moisture conditions at well 993.1–6W, south of Socorro*

SAMPLES TAKEN AT [illegible]

Depth in feet	Moisture in percent [illegible]	Pore space, in percent	Volume weight	Moisture equivalent, in percent [illegible]	Average
0–0.5	[illegible]	63.7	1.19	[illegible]	[illegible]
0.5–1.0	26.5		1.19	23.5	
1.0–1.5	[illegible]	[illegible]	0.98	30.7	37.5
1.5–2.0	51.4		0.98	44.4	
2.0–2.5	42.0	[illegible]	1.14	37.6	38.7
2.5–3.0	48.3		1.14	39.9	
3.0–3.5	[illegible]			[illegible]	
[illegible]	[illegible]			36.3	

SAMPLES TAKEN AT 7:40 A. M., AUG. 20, 1936

0–0.5	31.0	[illegible]	1.44	14.0	12.5
0.5–1.0	21.9		1.44	11.0	
1.0–1.5	41.0	[illegible]	1.07	31.3	34.8
1.5–2.0	[illegible]		1.07	[illegible]	
2.0–2.5	47.9	54.0	1.14	35.0	[illegible]
2.5–3.0	52.2		1.14	37.2	
3.0–3.5	[illegible]	65.6	0.86	43.5	43.6
3.5–4.0	79.3		0.86	43.7	

[8] Stearns, N. D., Laboratory tests on physical properties of water-bearing materials: U. S. Geol. Survey Water-Supply Paper 596, pp. 148, 149; 1927.

by means of pumping tests or otherwise. To express this case of movement through the entire thickness of the aquifer, the term coefficient of transmissibility will be used and will also be expressed in gallons a day. It equals the average Meinzer coefficient of permeability of the material in the aquifer multiplied by the thickness of the aquifer, in feet.

Darcy's law is in form the same as Ohm's law relating to the flow of electricity, and the same as the law relating to the flow of heat by conduction in solids. For every factor needed to use Darcy's law in the study of ground water, there is an analagous factor in the theories of the conduction of heat and electricity. In general, studies of the movement of ground water are for several reasons more complicated than studies of the movement of heat. Ground water moves through a medium made heterogeneous by geologic processes which were subject to interruption and variation during the period of formation of the medium, whereas problems in conduction of heat and electricity commonly concern more or less homogeneous media fabricated by man. Therefore, although it seems necessary to consider theoretically the movement of water as it would be in a homogeneous medium in order to have a criterion to apply to the observed phenomena, it must be remembered that no theoretical quantitative treatment can exactly express the conditions of movement of ground water in nature. However, the results of such theoretical studies yield criteria in the light of which observed phenomena can be interpreted, in much the same way as the theory of beams yields useful criteria for the construction of wooden structures although it is recognized that wooden members do not conform to the ideal structures of theory and a factor of safety must be applied for safe construction.

Any fluctuation of the water table should be interpreted in the light of changes that have occurred to the east, west, north, and south of it, and vertically below it, and also before it in time. For instance, the water levels observed in shallow observation wells that extend just below the water table generally show the hydrostatic head at the water table with considerable precision, but the head of the water at greater depths in the water-bearing formation may be significantly different, because there is likely to be a vertical pressure gradient even where no artesian structure exists. Again, in nearly all ground-water phenomena there is a lag effect. Many phenomena are not correlated with contemporaneous phenomena elsewhere, but with phenomena of the past. As one instance in point, there must always be a time interval between the rise of the water level in the Rio Grande and the rise of the water level in the riverside drains, and it is therefore probable that the drains generally reach their maximum stages during falling stages of the river.

In homogeneous material the ground water moves in the direction of the slope of the water table. However, by Darcy's law the rate of flow is equal to the pressure gradient multiplied by the coefficient of transmissibility and hence in a material that has different transmissibility in different directions, the direction of movement must be deflected from the slope of the water table toward the direction of greater transmissibility.

The medium through which the ground water chiefly moves in the Rio Grande Valley is the alluvium deposited by the river. An aggrading river, such as the Rio Grande, deposits coarse materials under its channel and finer materials on the adjacent flood plain. When the river shifts its course, it scours out some of the flood-plain materials and deposits coarse materials in their place, at the same time depositing finer material over the coarse material in its abandoned channel. Water moves longitudinally through these more or less continuous coarser deposits with comparative ease, but its movement either vertically or transversely to the axis of the valley is retarded by the less permeable flood-plain deposits between the old channelways. The application of this principle to the present study lies chiefly in the interpretation of the maps of the water table, with respect to the direction of the movement of the ground water. In the absence of definite data, it seems to the writer a fair tentative assumption that, in general, the direction of movement is at perhaps about half the angle with the river as that of the water-table gradient as shown by the contours of the water table on the map. If it were possible to construct a water-table map that would be accurate in minute detail, the slope of the water table at any given place, as indicated by the contours, would correspond essentially to the direction of movement of the ground water.

General Character of the Movement

The most obvious characteristic of the ground-water flow indicated by the water-table map and the foregoing discussion is its predominant downstream movement. From the vicinity of Algodones at milepost 880, on the Atchison, Topeka & Santa Fe Ry., where the water table has an altitude of 5,080 feet, to milepost 997, 17 miles south of Socorro, the water table falls 585 feet, or an average of 5 feet to the mile. In places where ground-water recharge occurs, whether from the river, irrigated land, canals, or bordering mesas, the hydrostatic head is built up and consequently there is a tendency for the ground water to move laterally away from these places and also vertically downward. In places where ground water is discharged, whether by vegetation or drains, the head is lowered and consequently there is a tendency for the ground water to move laterally toward these places and also vertically

upward. Thus the body of ground water is slowly but constantly moving in a general downstream direction, receiving new supplies at some places and losing water at others. Thus the ground water discharged at any place may have had its origin a considerable distance up the valley and may have been brought to the points of discharge through a certain amount of upward as well as lateral movement.

The lateral slopes of the water table, and consequently the lateral movement of the ground water, vary considerably in the different parts of the valley, depending principally on the spacing of the drains. In general, the lateral slope of the water table varies more or less inversely with the width of the valley. The lateral slope is greatest in the Socorro division, where it is as high as 22 feet to the mile, and least in the Belen division. The interior drains in general follow the cienegas, or longitudinal depressions of the flood plain between the borders of the valley and the natural levees of the river. As a consequence, the interior drains are generally incised into land that is lower than the land near the river and in most places lower than the river itself. Hence the water table is here held at its lowest position. Where the valley is narrow, and where the cienega and the drain are consequently close to the river, the gradients from the river to the cienega and from the border of the valley to the cienega are consequently high. The riverside drains are generally on higher land than the interior drains.

Movement Near Riverside Drains

In probably the greater part of the valley the slope of the water table is from the vicinity of the riverside drain toward the interior drain. In the areas where the valley is narrow and the interior drain is only a fraction of a mile from the riverside drain, the slope toward the interior drain is especially great. Many of the canals and laterals closely parallel the riverside drains, and hence wherever there is considerable seepage from the canals or laterals, the ground-water level is held high and causes or accentuates a slope from that vicinity toward the interior drains. In some localities the canal near the riverside drain may be the principal source of the ground water flowing from it in the direction of the interior drain. In some irrigated localities seepage from the water applied to the land may be the principal source but in the Socorro division, where the gradient toward the interior is greatest, there is comparatively little irrigated land near the river. There is also a tendency for water from the river to underpass the drains and to continue percolating to lower hydrostatic levels farther inland.

In connection with the study of the lateral slope of the water table, several observation wells were established in the close vicinity of the Socorro riverside drain opposite milepost 976.5, 1 mile north of Socorro. These wells were placed on a line at right angles to the drain, at intervals of approximately 142, 358, and 554 feet west (inland) from the drain, and 153 and 380 feet east from the drain in the direction of the river, which is about one-fourth mile from the most easterly well. The wells are in a bosque. The line of wells is crossed by the Socorro main canal, and one of the wells (976.5–3W) is very near the canal. There was, however, no irrigation near these wells. Graphical records of the water levels in these wells are given in figure 63.

At the time of the first readings on May 11, 1936, the water levels in wells inland from the drain stood at their highest position during the period of observation, and in the wells between the drain and the river the water levels were nearly but not at their highest position. The water level in the drain stood about 1.1 feet below a line connecting the water levels in the nearest wells on the opposite sides of the drain. Minor fluctuations were recorded during the remainder of May. On June 2, the water level at the well nearest the river had risen about 0.5 foot with respect to its position on May 18. At the same time the water level in the well farthest inland had fallen about 0.4 foot and the relative level of the drain remained the same. The rise of the water in the one well was probably due to flooding by the river and the fall in the other to increased transpiration losses. On June 27 the water level had fallen about 0.2 foot below its initial position in the well near the river and about 0.7 foot on the inland side. The water level in the drain was still about 1.1 feet below the position indicated by the average gradient between the adjacent wells. On July 29 the water near the river was 0.5 foot below its original position and farthest inland it had fallen to its

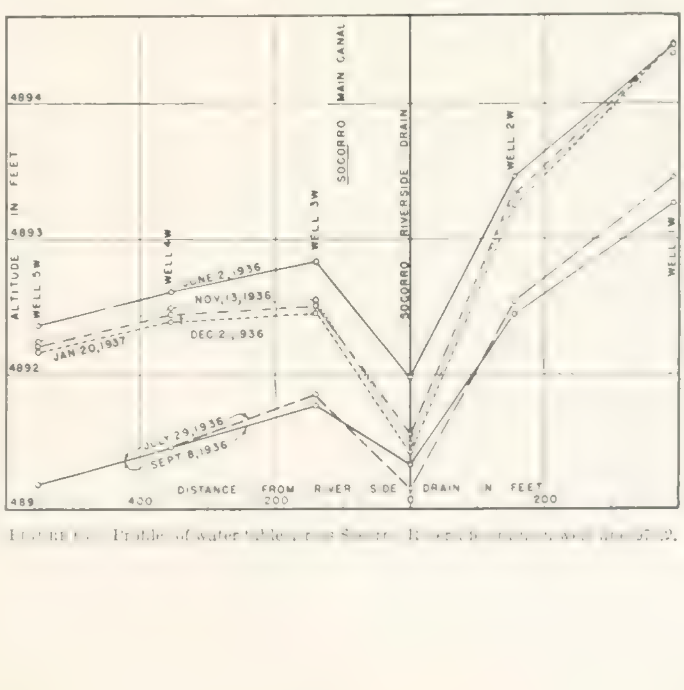


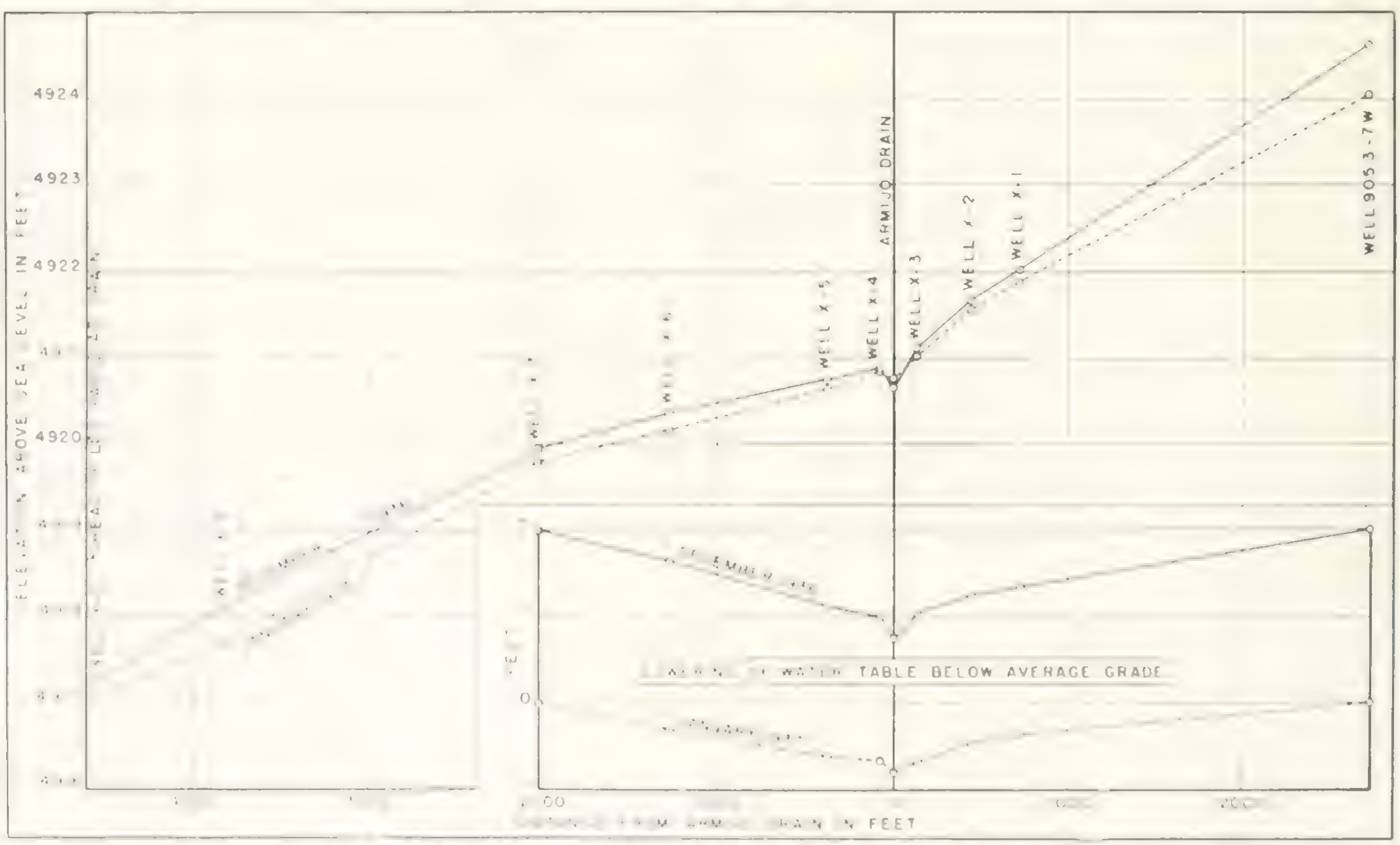
FIGURE 63.—Profile of water table [illegible]

[illegible] feet below its level when first observed. The water [illegible] position indicated by the average grade between adjacent wells. This approximate position was maintained through August and a part of September. On October [illegible] intermediate between the extremes shown during the period of reading. The water level in the drain was 1.1 feet below the position indicated by the gradient between adjacent wells. On November 13 the water level had risen almost to its highest position near the river and about 0.4 foot below its highest position at the land end of the line. The water in the drain stood about 1.4 feet below the position indicated by the grade between adjacent wells. On November 16 the canal, which passes between well 3–W and the riverside drain, was closed. There was practically no change in the position of the water table between the previous reading, on November 13, and the next reading, on December 21.

The slope of the water table between well 3–W and the riverside drain indicates that water is moving toward the drain near the water table in this interval. The slope in the opposite direction between wells 3–W and 5–W indicates that water is moving away from the river in that interval. Such a condition would be explained by the presence of a source of ground water at or near well 3–W, such as seepage from the canal. However, in well 3–W, near the canal, there was a relatively large decline in the water table between June 2 and September 8, while the canal was continuously filled with water and there was little change in its position between November 13 and January 20, 1937, although the canal did not carry water after November 16. The decline in the wells prior to September 8 was probably due to discharge by the native vegetation, and the subsequent rise was probably due largely to replenishment by ground water from farther up the valley—in part, water from the river that underpasses the drain.

Movement Near Interior Drains

Figure 64 shows the profile of the water table along a north-south line of experimental wells across Armijo drain, on the west side of the river, about 3 miles below Albuquerque, about midway in its course westward to join the Isleta drain. It shows a fairly uniform gradient along most of the profile, except near the drain, where the gradient is greatly increased as the water converges laterally and upward to the drain. This is probably a typical profile of the water table near an interior drain.



Coefficients of transmissibility may be computed from the flow in interior drains and the water-table gradients near them. In this case the sum of the gradients on the two sides of the drain toward it are equal to the pick-up of the drain divided by the transmissibility of the aquifer. If the pick-up of the drain is expressed in second-feet per mile and the gradient as a decimal, the coefficient of transmissibility will equal the pick-up divided by the sum of the gradients on the two sides and multiplied by the factor 122.

Some difficulty has been experienced in finding suitable localities in which to make this comparison. Wells used to determine the gradient must be so placed that no interfering source or outlet of ground water occurs between them, and the drains must be capable of being measured with some accuracy. The best locality found was that of the Barr interior drain. Three lines of wells cross this drain, and good records have been obtained on all of them. The data on water-table gradients in this area are given in table 5.

TABLE 5.—*Water-table gradients between certain wells in the Barr district*

Date (1936–37)	Water-table gradient between wells						
	909.6-6E and 909.6-7E	909.6-10E and 909.6-9E	910.2-4E and 910.2-5E	910.2-7E and 910.2-6E	911.2-5E and 911.2-6E	911.2-9E and 911.2-8E	Double average
May 25	[illegible]	0.00496	0.00092	0.00327	0.00036	0.00050	[illegible]
June 18	.00196	[illegible]	.00067	.00599	[illegible]	.00027	.00410
July 17	[illegible]	.00491	.00072	.00444	−.00044	.00007	[illegible]
Aug. [illegible]	[illegible]	[illegible]	[illegible]	.00565	[illegible]	[illegible]	.00400
Sept. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.00044	[illegible]	.00364
Oct. 20	[illegible]	[illegible]	.00244	.00411	−.00004	[illegible]	.00470
Nov. [illegible]	.00163	.00436	.00186	.00382	.00102	.00027	[illegible]
Dec. [illegible]	.00157	.00357	−.00015	.00419	.00107	[illegible]	.00338
Jan. [illegible]	.00142	.00346	−.00097	.00284	.00111	.00043	.00277
Distance between wells in feet	[illegible]	740	[illegible]	[illegible]	225	300	
Distance between nearest well and drain in feet	[illegible]	[illegible]	580	122	[illegible]	[illegible]	

The double average gives the average sum of the gradients on both sides of the drain on the three lines of wells. Gradients toward the drain are considered positive in the tabulation. The double average is plotted on figure 65, together with rates of accretion to the Barr drain taken from exhibit T–33 entered in the present suit between Texas and New Mexico on the adjudication of waters of the Rio Grande. The average monthly values for the two sets of data are given below.

TABLE 6.—*Average sum of water-table gradients toward Barr drain, average pick-up of the drain, and computed coefficients of transmissibility of the aquifer*

Month	Average sum of water-table gradient	Average accretion to drain (cubic feet per second per mile)	Computed coefficient of transmissibility
June	[illegible]	3.07	[illegible]
July	[illegible]	2.23	71,700
August	.00391	2.46	76,800
September	.00378	2.22	71,400
October	[illegible]	1.98	53,800
November	.00431	2.07	58,600
December	.00369	1.57	[illegible]
January	[illegible]	[illegible]	[illegible]

Beginning with October the computed coefficients of transmissibility are quite accordant. There seems to be little doubt that they are more nearly correct than those computed for June to September, for the summer water levels are influenced by irrigation, which is irregular and furthermore adds water between the wells, whereas the theory assumes that the same amount of water passes the successive wells. Inasmuch as more water is likely to be added to the best drained land, which is land near the drain, the tendency is to make the ratio between the pick-up of the drain and the water-table gradient larger

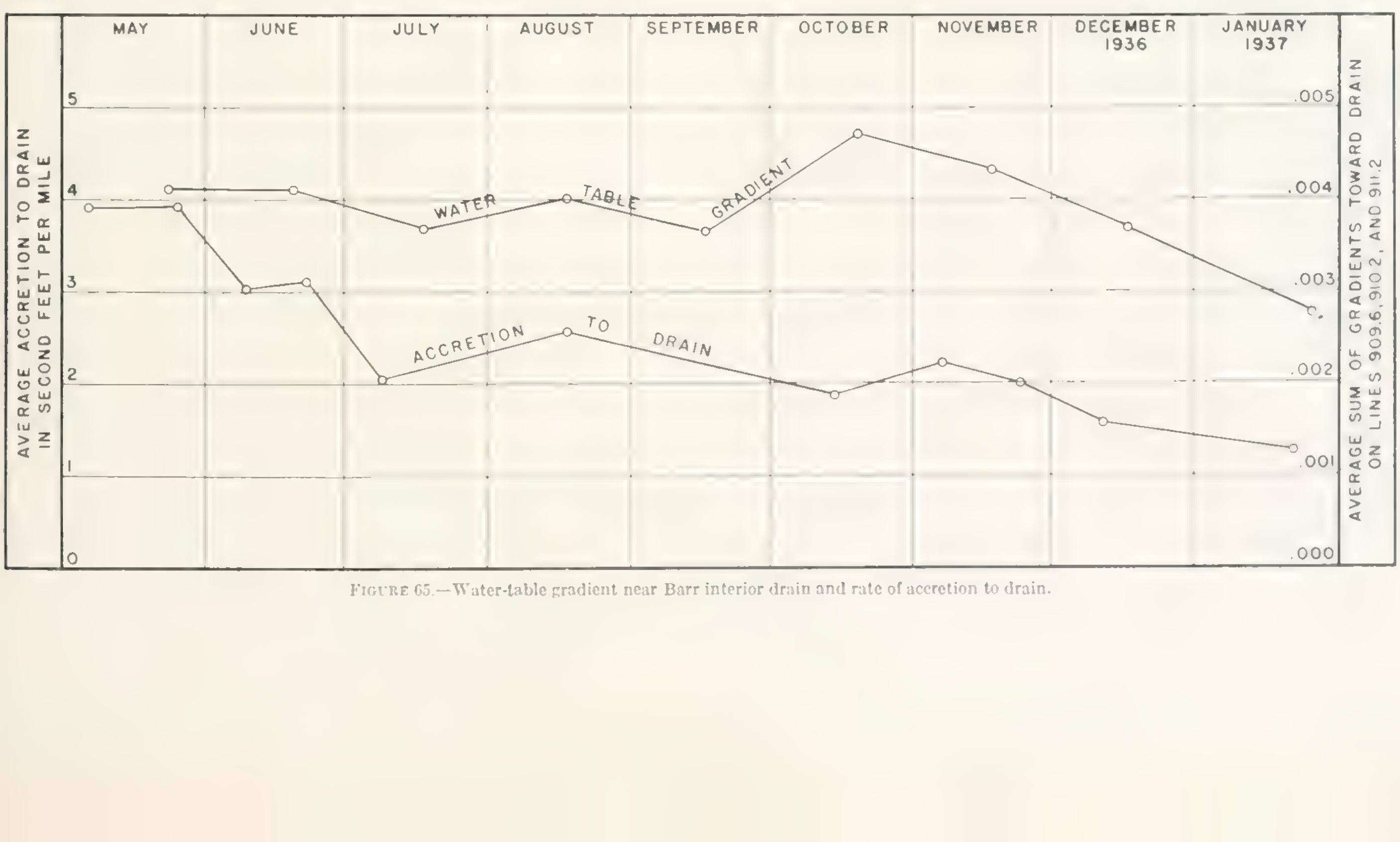


FIGURE 65.—Water-table gradient near Barr interior drain and rate of accretion to drain.

in the irrigated season than at other times. During the nonirrigation season water is taken from storage between the wells chosen to measure the gradient and between the nearest well and the drain. The gradient between the wells therefore corresponds to a smaller quantity of water than enters the drain.

It is therefore believed that the coefficients of transmissibility computed from the data for October to January are more nearly accurate than those computed for June to September, but that even these are somewhat too large. It seems to the writer that a coefficient of 50,000 is likely to represent approximately the average transverse transmissibility of the alluvium of the area and perhaps that of the alluvium in the Middle Rio Grande Valley, but intensive work on this particular problem is needed.

Source of the Ground Water

Ground Water From the Bordering High Lands

The ground water in the Middle Rio Grande Valley has several sources, namely, underflow from the mesas on both sides of the valley, seepage from the river, seepage from the canals, local rainfall, and seepage from irrigated lands.

A considerable amount of ground water in the aggregate must come from the higher lands bordering the valley. A part of the rain that falls on the extensive mesas on both sides of the Rio Grande Valley percolates down to the water table. This is proved by the presence of wells on the mesas with higher water levels than those in the wells in the valley. The only obvious avenue of escape for this water is in the valley. In many places, such as on the east side of the river at Albuquerque, any other disposal is almost certainly prevented by granite masses in the mountains bordering the Rio Grande depression.

Ground water percolates from the bordering highlands into the water-bearing alluvium or fill that underlies the valley and thence comes near the surface and is eventually discharged by the drains or by the vegetation or in other ways. There is doubtless general percolation toward the valley throughout the length of the valley, but the largest contributions come from the vicinities of the arroyos, which intermittently carry large quantities of water. The water-table map shows steep gradients near the debouchures of the large arroyos upon the floodplain, notably below Tijeras Canyon, in the upper part of the Barr district, and near Hell Canyon, above Peralta.

Observation wells were placed in the valley of an arroyo entering the Rio Grance Valley at the north line of the Bosque del Apache Grant and in the valley of the San Antonio Arroyo, above San Antonio. It was hoped that these arroyos would discharge surface water during the course of the investigation, and that significant fluctuations of the water table would be found. However, they did not discharge any water and the only fluctuations noted were similar to those of other parts of the valley.

In many places the water table under the valley near the mesas has a considerable gradient—generally larger than that in the interior of the valley. This indicates considerable ground-water flow, but some part, perhaps a large part, of this is furnished by seepage from high-line canals. It seems impossible to apportion the flow to the two sources with the data at hand, but intensive study in chosen localities of water-table fluctuations when the canals are full and when they are empty might yield results. Studies of the quality of the ground water near the drains might also be indicative of the source, but samples from shallow wells are likely to show only the last increment to ground-water flow; that is, the increment furnished by the canals. Studies of the gradient of the water table under the mesas and of the permeability of the Santa Fe formation underlying them would help answer the question. A study of water-table gradients on both sides of the high-line canals would also be useful, but as the critical canals are on high ground, this would require the use of well-drilling equipment to sink the observation wells.

Some of the water percolating through the permeable beds of the Santa Fe formation below the mesas doubtless enters the fill below the valley at considerable depths, eventually rising through the valley fill throughout the width of the valley, and having a part in maintaining the general ground-water level and supplying the drains. As the river flows at a higher level than the ground-water level in the cultivated area and as the flow is from the river toward the land, little if any of the flow from the mesas can escape between the riverside drains. In winter when transpiration and evaporation are very low, most of the water from the mesas is returned to the drains. At this time there is no irrigation but there is perhaps a small amount of recharge from melting snow. There is little water lost by transpiration. Hence the flow of the drains at this time is maintained largely by ground-water flow from the mesas and from the river.

The recharge from the mesas, as well as the specific yield of the valley fill, was computed for the section of the valley between Isleta and Belen by assuming that during this winter period the recharge from precipitation and the discharge by evaporation and transpiration are negligible and that the quantity of water from the river that underpasses the river-side drains approximately compensates for the seepage into these drains from other sources (pp. 285–286). This portion of the

valley is the widest part of the middle valley, and, throughout its length of about 17 miles, irrigated land and drainage structures are present on both sides of the river. The total flow of the interior drains the Los Lentes and Los Chaves drains, west of the river, and the Otero, San Fernandez, and Tome east of it—was 50.5 second-feet on December 15, 1936, 37.7 second-feet on January 23, 1937, and 32.8 second-feet on February 25. The average fall of water level in 81 apparently typical wells in this part of the valley was 0.46 foot from December 15 to January 25, and 0.17 foot from January 25 to February 17. The area under consideration contains about 36,000 acres, and therefore approximately 16,600 acre-feet of material was unwatered in the first period, of 41 days, and 6,130 acre-feet in the latter period, of 23 days—equivalent to 405 and 266 acre-feet a day, respectively. The average rate of discharge of the interior drains was 44.1 second-feet in the first period and 35.3 second-feet in the second period. On the foregoing assumptions, the water discharged by these drains must have been derived essentially from ground-water flow from the mesas and removal from storage by lowering of the water table. The rate of flow from the mesas was presumably almost constant. Therefore, the following equations can be written:

$$\text{Mesa increment plus } \frac{405 \text{ times specific yield}}{1.984} \text{ equals } 44.1$$

and

$$\text{Mesa increment plus } \frac{266 \text{ times specific yield}}{1.984} \text{ equals } 35.3.$$

In these equations 1.984 is the factor for converting from acre-feet a day to second-feet. These two equations can be solved simultaneously to give a mesa increment of 18.3 second-feet, or 1.08 second-feet per mile of valley, and a specific yield of about 12.5 percent.

The movement of ground water in the Rio Grande Valley is complicated because of the number of possible sources and possible outlets, and hence the solution of the pair of simultaneous equations above can be only indicative of the magnitude of the quantities involved. The mesa varies from point to point in its width, intake possibilities and water-carrying capacity and therefore the increment of water from the mesa will vary accordingly. When more data for several stretches of mesa and covering a longer period are available the method used may give good results. There are several possible sources of error. Probably the most important of these is the lack of information as to the amount of ground water from the cultivated area that is tributary to the riverside drains, and, conversely, the amount of water from the river which underpasses the riverside drains. If any recharge occurred in February coincident with the thawing of the ground it decreased the lowering of the water table and as a consequence the computed specific yield is less than the actual and the computed mesa increment larger than the actual.

The data available regarding ground-water conditions before the construction of drains is shown on page 291 to indicate an average mesa increment of from 0.5 to 1 second-foot per mile of valley. Despite the large element of doubt in both methods used to determine the mesa increment the results are comparable. The increase in flow in the Rio Grande canyon between State Line bridge and Embudo indicates a ground water accretion amounting also to about 1 second-foot per mile (p. 224). This argeement helps to corroborate the estimate for mesa seepage in the middle valley, indicating at least that it is of the right order of magnitude. However, direct comparison of ground-water accretions in the two stretches of the river cannot be made because of differences in rainfall and in opportunity for recharge and discharge in the two localities.

A question of probably more direct importance than the actual amount of ground-water contribution from the bordering mesas, is the question as to the increase that may have occurred because of the lowering of the water table by drainage. The lowering of the water table at any point begins a lowering of hydrostatic pressures in all three dimensions that gradually extends farther and farther from the initial point and causes flow from more remote localities. As the water coming into the drained area moves from more and more distant localities, the gradient under which it moves decreases. Hence, with the lowering of the water table in the valley by drainage, the quantity of ground-water inflow from the mesas must have been increased by withdrawal of ground water from storage, and then gradually decreased from the maximum. Eventually, a new equilibrium will be approximately established.

It is obvious that the construction of drains in the Rio Grande Valley has not added new sources of ground water to the bordering highlands. The lowering of the water table in the valley may cause the diversion of some water which formerly percolated underground to some point of discharge other than the Rio Grande. However, in much of the Middle Valley there is no other possible outlet, and when a new equilibrium is established there will be little if any more flow of ground water to the valley than there was under the old regimen.

How will the flow to the valley and hence to the drains vary during the period before equilibrium is attained and water is being withdrawn from storage in the mesas? An approximate answer to this question can be drawn from the mathematics of heat conduction in solids. Darcy's law for ground water is formally the same as that describing the flow of heat in solids. In heat conduction the factors necessary for the quantitative solution of a problem are the temperature gradient, the thermal conductivity of the medium and

its specific heat. These are analagous respectively in the theory of ground-water movement to pressure gradient, transmissibility, and specific yield. Hence, the analogs to many problems in ground-water hydrology have already been solved in the theory of heat conduction. One is the problem considered here.

If the water table at the edge of the valley is rapidly lowered by the construction of an interior drain, causing additional flow from the broad mesa bounding the valley, we have the same type of condition as when the temperature of the edge of a broad plate at a previously uniform temperature is suddenly lowered a fixed amount, except for minor differences in transmissibility produced by lowering of the water table. In the type problem it is assumed that the plate is infinite in width, that its initial temperature was θ_0 and that the edge of the plate is brought to a temperature of 0. Under these conditions the rate of flow of heat to the edge is[1]

$$W_0 = \frac{K\theta_0}{h\sqrt{\pi t}}$$

in which

W_0=rate of flow of heat to the edge.

K=coefficient of thermal conductivity.

θ_0=initial temperature of plate.

$h = \sqrt{\frac{K}{c\rho}}$

$c\rho$=specific heat per unit volume.

t=time measured from beginning of withdrawal of heat.

This may be integrated to give the amount of heat, M, passing the edge in any interval of time.

$$M = \frac{2K\theta_0}{h\sqrt{\pi}}(\sqrt{t_2} - \sqrt{t_1})$$

in which t_1 and t_2 are the times at the beginning and end of the interval.

This equation can be transposed to the realm of ground-water hydrology by the introduction of dimensional constants, giving

$$C = [illegible]\, A\sqrt{ST}(\sqrt{t_2} - \sqrt{t_1})$$

in which

C=acre-feet of water contributed per mile.

A=amount of lowering of the water table at the drain, in feet.

S=specific yield of material.

T=coefficient of transmissibility.

t_1, t_2=beginning and end of time interval, measured in years, since water table was lowered.

The form of this equation is at present more important than its arithmetical solution, as the several factors involved are not well enough known to give an accurate solution. Time enters as the difference of the square roots of the limits of the interval under consideration. This means that insofar as the conditions of nature approximate the ideal conditions assumed in the mathematical analysis, equal quantities of water were or will be withdrawn from storage under the mesas in the first year after the construction of the drains, in the next three years, in the next 5 years after that, 7 years, 9 years, and so on. In other words the excess rate of inflow from the mesas (over the normal rate) should vary inversely as the square root of the time since the drains were constructed.

If it were assumed that the water table has been lowered 4 feet at the drains near the mesas, that the coefficient of transmissibility of the mesas is the same as that indicated for the part of the valley traversed by the Barr interior drains, that is, 50,000—an assumption that may be quite erroneous—and that the specific yield is 10 percent, then the ground-water flow from the mesas in the sixth year after the construction of the drains would be 58 acre-feet per lineal mile of valley boundary per year greater than before the construction of the drains. The increase of flow of the drains near the hillsides would be somewhat less than 0.1 second-foot per mile. It is emphasized that the above treatment is a theoretical treatment and that quantitative statements made in it are not to be considered absolute statements of actual conditions in the valley but are to be used as indications of quantities and behavior to be expected.

Ground Water From Other Sources

In most areas of the middle valley, seepage from irrigated lands is doubtless the main source of supply of ground water. This is indicated by the pronounced drop in ground-water levels in irrigated districts from July, when there was heavy irrigation, to October, when irrigation had decreased although the canals were still operating. This trend is opposite to that occurring in unirrigated areas of natural vegetation. Table 2, page 274, gives the change in average ground-water level between July and October 1936. The Socorro, San Antonio, and Bosque del Apache areas represent areas of little irrigation; the other areas are more or less heavily irrigated.

In the section of this report on the areal description of the recharge, movement, and discharge of the ground water (pp. 286-289), different localities are pointed out where there is evidence of ground water derived from the river. Other localities are discussed where the

[1] [illegible]

presence of canals bordering the riverside drain makes it doubtful whether the river or the canal is the source of the water which is moving from their vicinity. Generally it may be said that the river is likely to be a source of water on the inland side of the riverside drains in areas where interior drains lie within a mile of the riverside drains, and that this condition is most prevalent in the Socorro division.

As mentioned previously, irrigation canals are present in many places close to the riverside drains, and their location here often corresponds with that of a crest in the water table. Water-table divides approximately follow the canals in a number of places in the interior of the valley. In some places this is probably due to more intensive irrigation near the canal, but many of the crests are probably caused by canal seepage.

The Middle Rio Grande Valley has an average annual rainfall of only about 8 inches, which occurs largely in the growing season when there is least opportunity for the rain water to penetrate to the water table. Therefore, it is probable that only a small amount of the ground water has its origin in the local rainfall. Rainfall does, however, have a noticeable effect in reducing ground-water consumption by the vegetation, and this effect is manifested in the rise of the water table during or after relatively light summer rains. Figure 5, giving the fluctuation of the water table near Socorro during the week following August 17, 1936, shows a decided rise of the water table after a rain of only 0.14 inch (at Socorro) on August 20. Similar rise of the water table was observed after each shower during the period of operation of the recorder. It should be noted that these rises are not necessarily due to recharge by the shower; they probably indicate chiefly a diminished draft on the ground-water supply by the vegetation—a substitution of rainfall for ground-water use.

Source of Water in Riverside and Interior Drains

Several lines of evidence show that the main source of water in the riverside drains is the river. The average accretion to the riverside drains is greater than that to the interior drains. The flow of the riverside drains follows the fluctuations in the flow of the river. As the river rises, the ground-water head between the river and the riverside drain is increased, with consequent greater ground-water flow from river to drain and, of probably more importance, the river during its rises also spreads widely over its bed and thus shortens the distance which the water must flow underground between river and drain. The chemical quality of the water in the riverside drains is much nearer to that in the river than it is to that in the interior drains.

The gradients between river and riverside drain are much steeper than those on the inland side of the drain. The gradients from the river to the riverside drains are not shown on the accompanying maps even where there are data, because the contours would be too close to be shown on a map of this scale. In the Albuquerque division, wells were established between the riverside drain and the river wherever feasible. There are no canals near the riverside drains that might furnish seepage to the ground water, on well lines 884.8, 894.4, 905.3 (east of the river), 907.3, 908.1, 911.2 (west of the river), and 911.8. On these lines the average gradient in October between the water levels in the wells nearest the river and in the water levels in the riverside drain was 0.0105, and the average gradient between the water levels in the nearest inland wells and the water levels in the riverside drain was 0.0018. The ratio of the gradient from the river to that from the other side was therefore 5.8. In January 1937, the average gradients from the river and from the inland side were 0.0086 and 0.0018, respectively, and their ratio was 4.8. Canals and other water carriers are present near the riverside drain on well lines 890.8, 892.5, 896.3, 898.5, 909.6, and 911.2 (east of the river), and exert an influence on the water levels inland from the riverside drain. On these lines, the average gradient in October was 0.0111 from the river and only 0.0007 from the inland side, yielding a ratio of 15.9, and in January, when the canals were empty, the average gradient from the river was 0.0122 and that from the other side 0.0011, yielding a ratio of 11.1. If the flow from the two sides of the drain is considered proportional to these gradients, the proportion of the drain flow coming from the river would be for the first set of well lines 85 percent in October and 82 percent in January, and for the second set, 94 percent in October and 92 percent in January. The implication of the data now available is that in the Albuquerque division the preponderant part of the water in the riverside drains comes from the river and that such accretions as come from the inland side may be offset in part at least by losses from the river to the interior drains.

Similar data are not available on ground-water gradients in the Belen and Socorro Divisions. However, the ground-water conditions between the river and the riverside drains in these divisions are not essentially different from those in the Albuquerque Division; there is about the same difference in elevation between the river and the riverside drains, and the intervening distance is on the average about the same as in the Albuquerque Division. Consequently, the rate of movement from the river to the riverside drain is probably about the same. On the whole, the water table in the Belen Division indicates less lateral movement of the ground water either from land to riverside drain or in the reverse direction than is indicated in the Albuquerque Division. Apparently the average accretion to the drain from the inland side is about the

same or perhaps slightly larger. In the Socorro Division there are in most places pronounced gradients from the riverside drains to the interior drains, and in this division, instead of accretions from the inland side to the riverside drains, there are probably losses from the drains to the land.

The ground-water data now available appear to indicate that only a small part of the water in the riverside drains in the middle valley originates inland from the drains. On the other hand, in several localities some river water appears to pass under the riverside drain to be transpired by vegetation or to emerge in the interior drains. These quantities appear to be of the same order of magnitude so that on the whole the discharge of the riverside drains, excluding surface waste into them, may represent approximately the quantity of ground water withdrawn by seepage from the river, while the discharge of the interior drains represents water derived from other sources. This tentative conclusion implied by the ground-water data should be checked against data concerning the chemical quality of the water in river, riverside drains, and interior drains when available.

Areal Description of Recharge, Movement, and Discharge of the Ground Water

Albuquerque Division

The present irrigating system of the Middle Rio Grande Conservancy District follows preexisting ditches in many areas. Some confusion in nomenclature of the various types of ditch results from the retention of the old names. The common Spanish name for a ditch largely regardless of size is acequia. Features still called acequias may take their water from the river, canals, or laterals. In turn, they may feed laterals or other acequias. In the following discussion, when referring to a specific structure the terms are used as used on the accompanying maps of the valley.

From well line 877 to 886.9 the water table slopes from the edge of the mesa to the river and indicates an accretion to the river from the arroyos and mesa slope and to some extent by seepage from the Bernalillo and Algodones acequias. The importance of seepage from the acequias as a source for the ground water is undetermined at present. The acequias are on high ground and the water table is so deep that it was found impossible to determine the gradients of the water table east of the acequias with the equipment at hand. When measurements of water levels during the winter months when the canals are dry are available, it may be possible to estimate the relative importance of the contribution of the acequias. The measurements for December 1936 and January 1937 suggest that the acequias have considerable importance in that the water-table gradients near them, on the whole, decreased somewhat after the acequias were closed.

The Bernalillo (interior) drain begins near well line 886.9. It is a short drain and empties into the Bernalillo riverside drain just below well line 888.5. It apparently intercepts most of the ground-water flow from the east and also receives some accretion from the river. Below the turn of the drain near line 888.5, where it begins its course laterally across the valley, the drain has been usually overfull during the period of readings and has apparently been feeding the ground water in this section. This feature is quite pronounced on plate 1, prepared from October measurements. The causes for this condition appear to be too low a gradient of the drain at this point and the presence of a large bosque area. Transpiration has apparently lowered the ground-water level here considerably below its normal position. The anomaly in elevation between water level in the drain and in the wells to the north became less in months succeeding October. For about 2 miles south of line 888.5 ground water appears to be flowing into the interior of the flood plain from both mesa side and river despite the presence of the Albuquerque main canal near the middle of the area. This appears to be due to the abstraction of ground water near the middle of the valley by the lower part of the Bernalillo drain and by the bosque area to the north.

In the Coralles area, west of the river, extending from well lines 890.8 to 894.4, around which the river makes a loop, the ground water by-passes some of the river water from one end of the loop to the other. Water apparently enters the ground from the river above line 890.8, although seepage from the Coralles main canal must oppose its flow, swings westward to the edge of the valley and returns again to the river in the lower part of the area.

East of the river, in the area between lines 894.4 and 896.3, the Alameda drain picks up a small amount of flow from the areas to the east and to the west. Apparently the major part of the ground water between it and the Albuquerque riverside drain passes into the latter drain. The Los Griegos drain heads just south of line 896.3 about one-fourth of a mile east of the riverside drain. It remains within less than a mile of the river to its junction with the Alameda drain south of line 899.8. Throughout this distance it apparently receives accretions from the river, as the slope of the water table on line 898.5 is from the riverside drain past the acequias. The area between the Alameda and Los Griegos drains is drained in a normal fashion to both sides. Judging by the low lateral gradients there appears to be only a small amount of inflow from the direction of the mesa to the drain.

From the junction of Los Griegos with the Alameda drain to the junction of the Alameda with the riverside drain south of line 901.5, the Alameda drain apparently receives some increment from the river.

The area in the city of Albuquerque was not surveyed. Because of the many artificial conditions in the city, including paving over a large area, sewers, pumping plants, and irrigation of lawns, the water table is abnormally distorted and is not typical of the area in general. The water table in most places in the city is deep and the expense of maintaining a system of deeper wells was not considered warranted.

The Barr district is a narrow strip of valley bottom on the east side of the river extending from Albuquerque to Isleta. Considerable water moves into this area from the direction of the mesa. This water is discharged into the riverside drain in portions of the area where there are no interior drains but is intercepted by the interior drains where present. As the Barr Canal lies to the east of the observation wells, it as well as ground water from the mesa may be the source of this water. Apparently it is the source of some of the water, for on well lines 909.6 and 910.2 the water table in the wells nearest the canal fell more than in neighboring wells in the period from November 1936 to January 1937, in the later part of which period the canals were dry. On the other hand, the reverse tendency was shown on line 906.1, where the water levels in the wells near the Barr Canal and the San Jose lateral fell less than in neighboring wells. A decision as to the main source of the water must be deferred until a systematic study of the fluctuations in water level near the mesas and high canals between irrigation and non-irrigation seasons can be made, and until seepage losses in the canals are determined. The Barr riverside drain is apparently effective in draining the land throughout its length and there appears to be no accretion from the river to the cultivated area.

The area between Albuquerque and Isleta on the west side of the river is called the Isleta-Atrisco district. The Isleta interior drain includes a short section of riverside drain at its head opposite Albuquerque. There appears to be some movement from the river above line 902.7, but inasmuch as the area is heavily irrigated, seepage water from irrigation may be the source of most of the water moving into the upper end of the interior drain. The Armijo drain heads south of line 903.2 and swings directly west to empty into the Isleta drain south of line 905.3. The distance between these two drains increases southward. As a result much of the water normally flowing south is diverted to the drains near the head of the Armijo and as a consequence less water continues south and the slope of the water table decreases. North of the westward flowing portion of the drain the slope of the water table increases and south of it the slope decreases as a consequence of the action of the drain. The Los Padillas drain heads near line 907.3 and runs south to join the Isleta drain between lines 911.2 and 912.5. Because of its nearness to the river, the water table gradually swings toward it and away from the river. In this area some water apparently moves from the riverside drain to the Los Padillas drain, the amount increasing toward the mouth of the Atrisco riverside drain just south of line 912.5.

Belen Division

The Belen division includes the widest part of the Middle Rio Grande Valley and in many places it includes land on both sides of the river. In general, the water table lies at somewhat less slope and is less distorted from a general southerly slope than in the other divisions, and there is less slope from the riverside drains to the interior drains.

The Peralta-Tome area lies on the east side of the river and extends from Isleta to a point opposite Belen, a distance of about 17 miles. The valley expands rapidly just below Isleta. The water table shows that the river is feeding the ground water for a distance of about 2 miles, probably as a result of the deficiency of the normal ground-water flow from the north where it is cut off by the hills at Isleta.

The Otero drain heads at the southern boundary of the Isleta Pueblo Grant, near well line 917.8. The crest of the water table roughly follows the Otero lateral, and this canal probably is the source of much of the water moving to the drain. The Otero drain and the Tome drain diverge southward between lines 917.8 and 920.5, and apparently as a consequence the gradient of the water table and the velocity of the ground water decrease. There is inflow of water from the east throughout this distance, either ground-water seepage from the mesa or seepage from the Chical lateral on the hillside. Hell Canyon opens on to the flood plain of the river at Chical and considerable ground water is probably coming from this arroyo.

South of line 925.4, Tome Butte juts out into the flood plain of the river and decreases the width of the valley east of the river to about one-half of that above. Between line 920.5 and this locality the ground water apparently receives accretions from the river which are small compared with accretions from irrigation and canal seepage. As the ground water approaches Tome Butte in its general movement down the valley, much of it percolates into the Tome drain, which here swings westward around the butte. The crest of the water table from line 925.4 to line 930.2 follows canals and laterals and apparently shows seepage from them. From this point to the southern end of the area the ground water has a component of flow toward the river

in part caused by seepage from the canal on the hillside and in part by the constriction of the valley in the downstream direction.

On the west side of the river, the area from Isleta to Belen is interlaced with canals. Seepage from one or another of the canals could cause any of the effects observed in the irregularities in the water table. In general in this area the ground water flows toward the river where there are no intermediate interior drains and away from it where there are. Apparently the water table is held high by seepage from the Belen high line canal as the valley begins to widen below well line 919.1, and by seepage from the Huning lateral above Los Lunas. Motion is toward the riverside drain between Los Lunas and the head of the Los Chaves drain. South of this point to well line 925.3 the ground water in general moves toward the interior drain, apparently little influenced by intervening canals. Farther south, to the mouth of the drain near Belen, the crest of the water table follows canal lines, and the ground water moves from the land to the riverside drain as well as to the interior drains, indicating loss of water from the canals and irrigated land to the drains. There is apparently considerable movement from the edge of the valley into the drains. The presence of the Belen high line canal on the edge of the mesa makes it probable that much of this water is derived by seepage from it. From Belen south to the lower end of the Sabinal riverside drain, near Sabinal, canal seepage and irrigation water furnish ground water that percolates both to the riverside and interior drains.

A narrow strip of land on the west side of the river between Sabinal and Abeytas is undrained. The scanty control for water-table elevations indicate that there is little lateral slope of the water table in the area, a condition which apparently existed in most of the middle Rio Grande Valley before drainage (see p. 289, and fig. 66).

The area between Abeytas and the Rio Puerco is poorly drained. Bernardo Lake is maintained at a high level and distorts the water table in its vicinity. There is practically no gradient of the water table from United States Highway 60 south to the Rio Puerco.

The San Juan-Las Nutrias area lies east of the river, about opposite the Abeytas-Puerco area on the west. At the upper end of this area the ground water is draining west to the river, probably because of seepage from the San Juan arroyo. Throughout most of the remainder of the area ground water moves from the river into the interior drain. On lines 944.6 and 945.3 the ground-water level near the riverside drain is higher than in the interior area despite the presence of [illegible] in the interior.

Socorro Division[1]

The Socorro division of the Middle Rio Grande Conservancy District comprises a narrow strip of land on the west side of the river between the constriction of the valley at San Acacia and the north line of the Bosque del Apache grant, where drainage structures end except for a prolongation of the San Antonio riverside drain downstream in order to obtain sufficient fall.

Because of the narrowness of the valley area in this division, the ground water moves from both sides to the interior drains under considerable gradient. Throughout the area canals and laterals border the riverside drains so that it is impossible to tell in most places whether the source of the water is seepage from the river or from these canals. In addition certain anomalous ground-water conditions exist due to disturbances in the drain flow.

In the upper part of the division in the area drained by the San Acacia drain, the water-table gradients are much flatter than ordinarily found in this division, presumably because of the interception of ground water coming from the north by the westward-flowing upper portion of this drain. Below the mouth of this drain the southerly gradient of the water table increases. The upper portion of the Polvadera drain causes a pronounced diversion of water from the direction of the river to it. The lower portion of the drain, south of about line 969.1, was ineffective as a drain at the time of observation, and the water level in the drain stood higher than the adjacent water table, presumably as a result of clogging of the drain at a culvert at the bend of the drain. From this point to the constriction of the valley at the Pueblitos crossing, flow from the direction of the river toward the mesa is indicated, with canal seepage or irrigation near the canals causing crests in the water table.

The Luis Lopez drain C begins just below the Pueblitos constriction within several hundred feet of the river. Relatively rapid flow of ground water into the drain from both sides is indicated by the steep slope of the water table. A portion of this water is probably derived from the river. The lower portion of this drain is also ineffective and was feeding the ground water at the time of observation

Between the mouth of the Luis Lopez drain A and the head of the short Luis Lopez drain B, the ground water tends to resume its general southerly course. The water is deflected toward drain B throughout its course and the movement toward drain B is strengthened by the checking of the Socorro riverside drain at its mouth to feed the Socorro main canal.

The Luis Lopez drain C which begins just south of well line 982, deflects the ground water to it in its

[1] See pl. 8

upper course but in its lower course, near line 986.2, it apparently, like most of the other interior drains of this division, is overfull and has little effect as a drain.

From the mouth of the Luis Lopez drain C to the end of the Socorro Division, at line 990.8, the ground water moves in general down the valley and has little transverse movement.

Bosque del Apache Grant [12]

The Bosque del Apache Grant is not in the Middle Rio Grande Conservancy District. It is undrained and practically unirrigated. It therefore furnishes types of ground-water phenomena which were presumably more or less characteristic of the whole valley before drainage.

The difference between the character of the water table, and hence the ground-water flow, in this area and in the developed area of the conservancy district is significant. The water table slopes rather uniformly southward and shows comparatively few irregularities, indicating that lateral flow of the ground water is small. The ground-water contours approach the river nearly at right angles, except near the mouth of the San Antonio riverside drain, where they are deflected by the adjustment of the water table between the grade of the drain above and that of the river below.

Considering the size of the area in which transpiration takes place, greater lateral gradients might be expected even in October when the readings represented on the map were made. Moreover, the lateral gradients on lines 994.1 and 995.1 on the last of June were not much greater than they were in October. This condition is probably due to the overflow of surface water. The Socorro main canal and the San Antonio riverside drain both contribute water to this area. The water runs southward and spreads out in ponds. This surface water no doubt furnishes much of the water used by the vegetation and keeps the water table built up in the center of the tract.

Ground-Water Conditions Before Construction of Drains

Previous Ground-Water Investigations

It was hoped at the beginning of this investigation that a detailed comparison could be made of ground-water conditions before and after the drainage developments were made in the Middle Rio Grande Valley. This hope has not been realized, but certain comparisons and contrasts can be made. Two comprehensive ground-water investigations had been made in the Middle Valley prior to the present one. In the period from 1918 to 1922, about 1,100 observation wells were installed by the State engineer of New Mexico, the New Mexico College of Agriculture, the United States Bureau of Agricultural Engineering, and several of the drainage districts. Water-level measurements in over 900 of these wells were made monthly or oftener. A bulletin based on these studies was later published by Bloodgood.[12a] The base data gathered during this investigation were never published but were kindly made available for the present study by Mr. Bloodgood, and by Prof. Fabian Garcia, director of the New Mexico Agricultural Experiment Station. The second investigation of ground-water levels was made in connection with the study preliminary to the installation of the Middle Rio Grande Conservancy District project. The results of this investigation were published by Donnell.[12b] The base data of this investigation were not available for the present investigation.

Direct comparison of the data from the Bloodgood investigation with those of the present investigation was in general impossible because of uncertainty as to the locations of the old wells, as there were no accurate maps of the valley prior to 1935 and most of the wells could not be located in the field because the old casings and markings had disappeared. As the water table sloped approximately 5 feet to the mile down the valley, a north or south displacement of the wells on the map to the extent of 1,000 feet from their true position in the field could cause an error in the indicated position of the water table of about 1 foot. Such an error would significantly affect the indicated lateral slope of the water table.

In a few areas enough of the old wells were found to give key localities for locating the remainder. One of the areas which was best covered with wells in the 1918–22 investigation was that between Albuquerque and Alameda. Figure 66 shows a map of the water table in this area based on the unpublished data of Bloodgood. The mean altitude of the water table through the period of record was used in making this map.

Seepage From the River Previous to Drainage

Figure 66 shows that previous to the installation of the drainage system, the ground-water contours in the area between Albuquerque and Alameda were nearly at right angles to the river, which indicates that in this area there was very little movement of ground water either into or out of the river during the period 1918–22. If this condition is typical of the valley it indicates that the amount of ground-water seepage from the river was small. Rough contour maps of the Belen and Albuquerque divisions for months showing high and low ground-water stages in the period 1918–22, plotted according to locations on the old maps, indicate flat lateral gradients. The undrained Bosque

[12] See pl. 9.

[12a] Bloodgood, D. W., [illegible]

[12b] Donnell, P. S., Report on ground-water determination: Middle Rio Grande Conservancy District Official Plan, Exhibit R-3, 1928.


NOTE DOTS REPRESENT WELLS IN WHICH ALTITUDE OF WATER TABLE WAS DETERMINED
ALAMEDA
VALLEY
4990
895
85
80
OF
RIO GRANDE
75
EDGE
70
RIO
65
APPROXIMATE
900
60
4955
ALBUQUERQUE

del Apache Grant shows the same low lateral gradients today. Bloodgood [13] gives typical ground-water profiles across the valley. The average gradient near the river as scaled from these diagrams is about 0.0006 in Bernalillo County, based on nine profiles; about the same in Valencia County, based on eight profiles; and about the same in Socorro County, based on the two profiles within the area covered by the present investigation. Some of the gradients represented in these profiles are known to be too because large wells near the river are north of the others used in constructing the profiles, but such errors are probably balanced by the displacement southward of wells near the riveron other lines.

If the coefficient of transmissibility were 50,000, as was tentatively estimated for the Barr district (p. 281), and if 0.0006 were assumed as the average gradient of the water table near the river before drainage was begun, a seepage loss from the river of about one-fourth second-foot per mile would be indicated. If the length of the valley between Pena Blanca and San Marcial is taken as 150 miles, the total seepage from the river on both sides before drainage was begun would have been 50,000 acre-feet a year.

Seepage from the Mesas Previous to Drainage

Although a final opinion should await additional data, a tentative opinion as to the amount of ground-water inflow from the borders of the valley previous to drainage can also be formed. Figure 66 indicates that in parts of this area where relatively good data are available, the ground-water contours approach the mesas only slightly deflected from perpendicularity, and such deflection as there is indicates in some places movement toward the mesas. There is therefore little evidence of movement from the mesas to the flood plain in this area. The contours in the Bosque del Apache area also approach the mesas near to perpendicularity, and little flow is indicated in this area where control is good. Averages of the water-table gradients from the mesa to the flood plain as shown on the profiles drawn by Bloodgood [14] are 0.0008 in Bernalillo County on the basis of eight profiles, 0.0003 in Valencia County, on the basis of seven profiles; and 0.0014 in Socorro County on the basis of two profiles. The general average is 0.00065. This general average gradient indicated is about the same as that from the river. Therefore, if the same transmissibility were assumed, the contribution of ground water from the mesas would have been about 50,000 acre-feet a year in the 150 miles between Pena Blanca and San Marcial. This figure might be increased somewhat to take into consideration concentrated flow near the debouchures of arroyos, on which data are scarce, and other unknown factors but it does not seem that on the above assumptions the inflow could have much exceeded 100,000 acre-feet a year. This last figure represents a contribution of about 0.5 second-foot per mile of valley border or about 1 second-foot per lineal mile of valley.

On pages 282-284, it is shown that the data now available on drain flows during winter periods suggest also that the ground-water flow from the mesas may be about 1 second-foot per lineal mile of valley. However, both sets of figures are subject to considerable revision as more data become available.

Seepage From Irrigation and Floods

If the foregoing estimates of river and mesa seepage are approximately correct, the much larger apparent loss of water from the river in this section must have been due largely to other causes, and there must have been other and more important sources of water to support the transpiration of the native vegetation. Losses from the river other than by seepage were by diversion for irrigation, spreading of the water and consequent infiltration during floods, and evaporation from the river channel, which was probably greater than now because of the present lowering of the water table between the levees. The first two of these processes made contributions to the ground-water supply in the valley and the spreading of flood water also furnished soil moisture that fed the native vegetation without reaching the water table. Diversion for irrigation was probably by far most important. There is apparently no good way of determining what former diversions were, but if the estimates here arrived at for ground-water flow are of correct general magnitude, the use of water on the land under cultivation was presumably large. The irrigators were doubtless constrained to irrigate when there was sufficient water in the river, and it would seem that they probably used quantities larger than necessary at such times in the hope of tiding over water shortages to come. This is somewhat the same principle as is used today in the "subbing" in the San Luis Valley. The water supporting the transpiration of native vegetation was probably derived largely from excess of water used for irrigation.

It was shown in the report by Bloodgood [15] that in the period covered by his investigation there was a direct relationship between variations in river surface levels and the fluctuation of the ground-water table. Prior to the construction of the El Vado Dam and permanent diversion structures in the valley, irrigation was largely dependent upon the stage of the river. Hence, the correlation noted was at least partly due to the agency of irrigation.

[13] Bloodgood, D. W., op. cit., pp. 21, 24, 29, 31, 38, 40, 42, 44, 49, and 51.

[14] Idem.

[15] Op. cit., pp. 58-60.

PART III

WATER UTILIZATION

Report of the United States Bureau of Agricultural Engineering [1]

Contents

[1] By Harry F. Blaney, irrigation engineer; Paul A. Ewing, irrigation economist; O. W. Israelsen, irrigation engineer; Carl Rohwer, irrigation engineer; Fred C. Scobey, principal irrigation engineer. A contribution from U. S. Department of Agriculture, Henry A. Wallace, Secretary; Bureau of Agricultural Engineering, S. H. McCrory, chief; Division of Irrigation, W. W. McLaughlin, chief.

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Section 6. The Vegetative Cover Survey

Section 7. Consumptive Use of Water Requirements

ORGANIZATION

The following permanent staff members of the Bureau of Agricultural Engineering participated in the Rio Grande Joint Investigation, under the direction of W. W. McLaughlin, Chief of the Division of Irrigation:

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PART III

SECTION 1.—INTRODUCTION

This is a report by the Bureau of Agricultural Engineering, made in compliance with the terms of its memorandum of agreement with the National Resources Committee, approved February 28, 1936. Therein the Bureau was charged with the principal duties of ascertaining the consumptive use of water in the major divisions of Rio Grande Basin above Fort Quitman, Tex., mapping the areas, and tabulating statistics of the lands in agricultural crops and water-consuming native vegetation and other areas using water in appreciable quantities. The report deals with these matters in two principal chapters which are preceded by such other discussions as are necessary to make it cover all the subjects specified in the agreement and provide a setting against which the two essential discussions will stand out clearly.

Synopsis

By the terms of an agreement with the National Resources Committee, approved February 28, 1936, the Bureau of Agricultural Engineering was charged with the two principal duties (among several, all of which are described in detail in this report) of ascertaining the consumptive use of water in the major divisions of Rio Grande Basin above Fort Quitman, Tex., and mapping and tabulating the areas in agricultural crops and water-consuming native vegetation. This report relates the results of the bureau's undertakings in discharge of these obligations.

Involved in the studies was a portion of Rio Grande's length totaling some 700 miles. A difference in altitudes of nearly 6,000 feet was also involved. So long a stretch and so wide a difference in elevations were marked by many variations of climate and soils and by wide differences and shifts in acreages and kinds of crops.

The waters of Rio Grande above Fort Quitman are largely consumed by native vegetation and irrigated crops in Colorado, New Mexico, Texas, and Mexico. In the usual year only a small portion of the total water production of the Rio Grande Basin above Fort Quitman escapes from it unconsumed, and that small part consists mostly of unusable return flow and flood-peak flows originating below Elephant Butte Reservoir.

There is considerable variability in the estimates made previously by engineers and others for unit values of consumptive use in the three major valleys of the basin. This variability is not extraordinary. It is difficult to make precise estimates because there are so many factors influencing the consumptive use. However, some variability in estimates is attributable to lack of specific definitions.

Most estimates for San Luis Valley are in reality estimates of stream-flow depletion rather than of consumptive use as defined by the Bureau of Agricultural Engineering to include annual precipitation and draft on ground-water supplies.

Not all the estimates by engineers, of use of water in Mesilla Valley are strictly comparable with each other. Some include the entire Rio Grande project, while others are concerned specifically and alone with the Mesilla Valley portion of the project. Experiments on the use of water on crops in Mesilla Valley have also been conducted by the New Mexico Agricultural Experiment Station and the Bureau of Agricultural Engineering for many years, and the results of these experiments likewise differ between themselves and with estimates of other investigators.

As defined by the Bureau of Agricultural Engineering, in a basic sense consumptive use is "the sum of the volumes of water used by the vegetative growth of a given area in transpiration or building of plant tissue and that evaporated from adjacent soil, snow, or intercepted precipitation on the area in any specified time."

As applied to the Upper Rio Grande Basin problem, valley consumptive use is considered equal to the amount of water that flows into a valley (or tract) during a 12-month year plus the yearly precipitation on the valley floor (or tract) plus the water in ground storage at the beginning of the year minus the amount of water in ground storage at the end of the year minus the yearly outflow; all amounts measured in acre-feet. The unit consumptive use of water per acre of irrigated land is equal to the consumptive use in acre-feet divided by irrigated area; and the unit consumptive use per acre of entire valley (or tract) is equal to the consumptive use in acre-feet divided by entire valley

(or tract) area. The unit use is expressed in acre-feet per acre or depth in feet.

The Bureau does not have available sufficient experimental data relative to rates of evaporation from soils following rains in the Upper Rio Grande Basin to constitute a basis for estimating the effectiveness of the rainfall. Therefore all the annual precipitation has been designated as a part of the consumptive use, it being recognized, however, that knowledge of the amount of stream-flow depletion (heretofore designated consumptive use by some writers) is of vital practical importance in the solution of Rio Grande water-use problems.

The amount of water which annually flows into a valley, or onto a particular land area, minus the amount which flows out of the valley or off the particular land area, is designated stream-flow depletion, and in a developed area is usually less than the consumptive use.

The consumptive use of water studies conducted by the Bureau of Agricultural Engineering in San Luis Valley, Middle Rio Grande Valley, and Mesilla Valley in 1936 may be considered as having two parts: First, analysis of available hydrologic data as a basis of determining consumptive use of water on large representative tracts or areas, these including past records and the results of field work during 1936; and, second, evapo-transpiration and evaporation measurements by means of tanks, and soil moisture studies, involving both native vegetation and irrigated crops.

Unfortunately funds to start the 1936 investigation were not available until April, and many of the field studies could not be gotten fully under way until the latter part of May. Thus in addition to being of limited significance because of representing only a single year, the 1936 results, especially those obtained from the tank and soil moisture studies, are properly subject to criticism because they are not completely representative even to that extent. Though their present applicability is thus restricted, they are here recorded to permit comparison and use with such other similar data as are now available or may later be accumulated. Further field studies throughout the basin, but especially in the Middle Valley, and extending over a much longer period, are needed.

The inflow-outflow method and the integration method were found to be the most satisfactory for estimating consumptive use of water for large areas.

The inflow-outflow method is probably the most reliable method to apply in San Luis Valley and Mesilla Valley. Conditions are less favorable for its use in the Middle Rio Grande Valley. However, the integration method will produce satisfactory results, if based upon careful estimates of unit consumptive use by the principal agricultural crops and native vegetation, and upon an accurate land classification.

Reliable data for determining use of water by the inflow-outflow method for a period of years were available only in part of San Luis Valley and in Mesilla Valley. The annual consumptive use determined by this method in the southwest area in San Luis Valley for the period 1925 to 1936 inclusive averaged 1.66 acre-feet per acre for the entire tract of 400,000 acres. In the Mesilla Valley it averaged 2.73 acre-feet per acre for the 18-year period 1919 to 1936. In the Isleta-Belen area, Middle Rio Grande Valley, less dependable data indicated a consumptive use of 2.7 acre-feet per acre for 1936.

Since data for determining consumptive use by the inflow-outflow method are obtainable only in certain areas of the Upper Rio Grande Basin, it is believed that with the data available, the integration method offers the best (or most feasible) means of estimating the present consumptive use requirements for the major subdivisions of the basin. However, the estimates presented in this report must be regarded as qualified by the following considerations: (*1*) Maps showing the vegetative cover and groundwater contours were not available when the estimates were made, nor were complete stream-flow analyses at hand; (*2*) final consideration had not then been given the results of the salinity studies by the Bureau of Plant Industry, which had as one important purpose the determination of the effects of saline water on irrigation requirements, and the extent to which it will be necessary, in some areas, to apply more irrigation water than is usually needed to meet the normal consumptive-use requirements, thus increasing the opportunity for evapo-transpiration losses; (*3*) the history of agriculture has been marked by so many drastic shifts as to suggest the possibility of future changes which will substantially alter the water requirements of the basin's major divisions. For instance, such alterations might conceivably follow extensive additional storage in Colorado; or economic or other events not now foreseen or predicted might bring about crop substitutions in Mesilla Valley as important as the relatively recent introduction of cotton.

Estimates of average annual unit consumptive use requirements (including precipitation) along the main stem of the Rio Grande, representing the present judg-

[illegible]	Average consumptive use, in acre-feet per acre, for			
	Irrigated lands	Native vegetation	Miscella- [illegible]	Total area [illegible]
San Luis Valley, Colo.	[illegible]	1.4	1.2	1.5
Colorado-New Mexico, State line to San Marcial, N. Mex.	2.6	3.6	3.2	3.2
San Marcial, N. Mex., to Fort Quitman, Tex.	2.8	[illegible]	3.7	3.2

ment of the Bureau of Agricultural Engineering, are as above (see tables 124 to 129, inclusive, for details).

The original plan for mapping the vegetative cover was much simpler than the plan finally followed. Essentially, however, the initial purpose of ascertaining the areas of irrigated land and other land "using appreciable quantities of water" was retained, and on the map which has been prepared the entire area between the lower fringes of the hills and bluffs along the main stem of Rio Grande through New Mexico and Texas was accounted for. Such limits were set for the work in Colorado as would keep the map from including areas which could not meet the stipulation of "using appreciable quantities of water."

Resulting from the vegetative cover survey were the following area totals, as of 1936. These results are in substantial accord with results of other surveys, especially in San Luis, Mesilla, and El Paso Valleys:

Location	[illegible]			
	[illegible] lands	Native vegetation	Miscellane- [illegible]	Total area [illegible]
[illegible]	[illegible]	737,199	109,210	[illegible]
[illegible]	152,782	140,910	73,217	[illegible]
San Marcial, N. Mex., to Fort [illegible]	[illegible]	70,062	38,625	[illegible]
[illegible]	[illegible]	[illegible]	221,052	2,092,817

Geographical Description

Rio Grande, rising in the San Juan Range, drains the mountain area east and south of the Continental Divide, in the south central part of Colorado. Its total drainage area in that State is 7,870 square miles. For some 80 miles its course is easterly as a mountain stream, until it enters San Luis Valley, a fertile, extensive, flat area lying between ranges of the Rocky Mountains. (Pl. 10.) This valley has a general elevation of 7,500 feet; the mountains surrounding it rise several thousand feet higher. Rio Grande cuts through it diagonally from northwest to southeast, and receives from the adjacent mountains the waters of nearly thirty streams, most important of which are Conejos River and Alamosa, La Jara, Costilla, Culebra, and Trinchera Creeks. A short distance north of the New Mexico line the river enters the long Rio Grande Canyon, through which it continues into that State. (Pl. 11.)

The drainage of the mountains bordering the northern part of the San Luis Valley is received by several streams, notably San Luis, La Garita, Carnero, and Saguache Creeks, which terminate in the north-central portion of the valley in a number of lakes having no visible outlets. This large area is accordingly referred to locally and by many writers as the "dead", "sump", or "closed" area, and in later sections of this report will be described by the last-mentioned term. The portion strictly tributary to Rio Grande is correspondingly known as the "live" area. (Pl. 11.) The greater part of this live area is in the southwestern portion of the valley, and frequent references will be made to it by that general expression. Similarly, the portion east of the river and south of the closed area will be referred to as the southeast area.

Many enterprises, large and small, divert water from the streams in the basin, for the irrigation of lands in all its portions. Notable in this connection is the fact that most of the irrigated farms in the closed area are served by canals diverting from Rio Grande. Some storage has been created on various streams; other storage possibilities are still under consideration.

San Luis Valley extends a short distance into New Mexico, and several of the smaller tributaries entering the river in Colorado rise south of the interstate line. Its most important tributaries in New Mexico are the Red (or Colorado), Hondo, Taos, Penasco, Embudo, Pojoaque, Santa Fe, Santa Cruz, Chama, Jemez, Puerco, and Salado rivers or creeks. (Pl. 1.) The narrow canyon through which the river flows in entering the State is succeeded by others, so that the first extensive agricultural area does not appear until it enters Espanola Valley, which centers in the town of that name. After again constricting its channel below Espanola Valley (pl. 12), the river emerges from White Rock Canyon at Cochiti.

There begins the Middle Rio Grande Conservancy District, the modern successor of a multitude of small irrigation systems which, for many decades preceding its creation, served valley lands extending some 150 miles nearly to San Marcial. (Plates 13–16, incl.) Important in the operation of the district's system is its storage at El Vado reservoir on the upper reaches of Rio Chama. (Pl. 1.) The headquarters of the district is Albuquerque, altitude of which is about 5,000 feet.

San Marcial, marking the lower terminus of the Middle Rio Grande Valley, is also the approximate upper limit of the lake created by Elephant Butte Dam, below which extend the several areas comprising Lower Rio Grande Valley. The Elephant Butte storage serves the lands in New Mexico and Texas making up the Rio Grande project of the United States Bureau of Reclamation. (Plates 18–21, incl.) Most important of these natural units are Mesilla Valley, which comprises the larger portion of the New Mexico half of the project, and El Paso Valley, which likewise includes the greater part of the project's area in Texas. (Pl. 20.) The two valleys are separated from each other by the narrow constriction just above El Paso, so that a part of Mesilla Valley is in Texas; and the pass is utilized as the site of a dam by which a portion of the river's flow

is diverted to Mexico. From El Paso to its mouth the river constitutes the international boundary. The altitude of El Paso is about 3,700 feet.

The New Mexico portion of the Rio Grande project is organized as Elephant Butte Irrigation District. The Texas portion is similarly organized as El Paso County Water Improvement District No. 1. The project's lower boundary is just above the El Paso-Hudspeth County line, and at this place the project delivers waste and drainage water to the canals of the Hudspeth County Conservation and Reclamation District No. 1, which serves most of the irrigated areas in Hudspeth County above Fort Quitman. (Pl. 22.) Some agricultural areas not under its canals are irrigated by individually owned farm systems. The entire valley area under present consideration includes none of the lands in Mexico, and none in the United States below the river gaging station at Fort Quitman, Tex. No considerable tributaries enter Rio Grande between El Paso and Fort Quitman in the United States. The altitude of Fort Quitman station is about 3,450 feet.

Involved in the studies here reported there was accordingly a portion of the Rio Grande's length totaling some 700 miles. A difference in altitudes of nearly 6,000 feet was likewise involved. So long a stretch and so wide a difference in elevations were marked by many variations of climate and soils and by characteristic diversifications in the agriculture which is the principal consumer of the river's water. Descriptions of some of these conditions appear in later sections of this report, notably those which affect the use of water.

HISTORY OF IRRIGATION DEVELOPMENT

Irrigation in the Rio Grande Basin above Fort Quitman had its beginnings many decades ago. In some localities it was practiced long before the coming of the white men. Not only are the remains of extensive irrigation works of unquestioned antiquity in evidence, but the early Spanish explorers found the Indians near Socorro and elsewhere in the Middle Valley, diverting and using water for the irrigation of their crops.

The Spanish settlers brought with them a considerable knowledge and experience in irrigation institutions and practice, which they proceeded to adapt to the conditions they found in the Southwest. The result was that the Spanish and Indian methods were blended, and out of this amalgamation arose irrigation practices and forms of organization which, in New Mexico, continued with little change until the existing systems were supplanted by the modern works of the Bureau of Reclamation and the Middle Rio Grande Conservancy District. Indeed, above the latter, long-standing agricultural practices have persisted to this day, and many of the older works are still in service.

In Texas and Colorado, the Spaniards were likewise active in extending their colonization and irrigation activities, but the total number of acequias and the area irrigated were relatively small. Some irrigation works in Texas were built in connection with mission settlements, but irrigation of Spanish origin in these two States is of small proportions in their present irrigation development.

San Luis Valley

The latter statement is especially true as regards San Luis Valley. (Pl. 11.) While irrigation had its beginnings there before the stimulation provided by the arrival of settlers from the Eastern and Southern States, the rise of the Valley to a position of agricultural importance took place abruptly during the last two decades of the nineteenth century. While properly subject, on the score of close accuracy, to the examination given it in later paragraphs, table 1 provides a statistical history of irrigation development in the Valley sufficiently illustrative for the present purpose.

Water Commissioner's Statistics

Table 1 presents not only the yearly totals of irrigated acreage in San Luis Valley from 1880 to 1936, but also the totals for each of the water commissioners' districts comprising irrigation division no. 3, the boundaries of which are those of that major portion of the Valley which is in Colorado.

Footnote 1 of table 1 shows the source of the statistics for the period 1880 to 1896 to be a report by W. W. Follett (20),[1] an engineer employed in 1896 by the United States Government to make a survey of the irrigation development of that entire stretch of the Rio Grande Basin in Colorado, New Mexico, and Texas with which the present report is concerned.

Several other statistical data which relate the progress of irrigation development in San Luis Valley are assembled in later tabulations, but these, with reference to each other and to table 1, betray a disconcerting lack of harmony. Mr. Follett discussed candidly the difficulties he encountered in assembling the figures for 1880–96, and in the portion of his report headed Résumé of Colorado Statistics (p. 72) expressed the following conclusions regarding them:

> It is likely that the total acreage given in these tables is within 10 percent of the amount cultivated during 1895 and 1896. * * * Prior to 1895, however, the statements of the acreage may not be nearer than 15 percent. * * * I think that these percentages of error in the totals are maxima, as a large error

[1] Figures in parentheses refer to [illegible]

TABLE 1.—*Area irrigated in San Luis Valley, Colo.*[1]

[illegible]

Year	District 20	District 21	District 22	District 24	District [illegible]	District [illegible]	District [illegible]	District 35	Total [illegible]
1880	[illegible]	15,100	24,100	[illegible]	34,100	16,680	4,000	2,640	131,475
1881	[illegible]	[illegible]	31,200	8,700	35,340	17,270	4,000	2,640	146,620
1882	[illegible]	[illegible]	[illegible]	[illegible]	35,950	17,600	4,000	2,640	165,085
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36,810	18,725	4,000	2,640	191,590
1884	[illegible]	[illegible]	[illegible]	[illegible]	39,120	20,380	4,000	[illegible]	201,155
1885	[illegible]	[illegible]	[illegible]	[illegible]	39,450	[illegible]	4,000	2,670	213,210
1886	[illegible]	[illegible]	[illegible]	[illegible]	39,930	21,230	4,000	2,890	[illegible]
1887	[illegible]	[illegible]	[illegible]	[illegible]	40,950	22,210	4,000	2,890	247,125
1888	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22,505	4,000	4,040	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22,505	4,000	4,520	[illegible]
1890	[illegible]	[illegible]	[illegible]	[illegible]	45,950	22,505	4,000	4,780	[illegible]
1891	[illegible]	[illegible]	[illegible]	[illegible]	46,750	21,430	4,000	4,780	[illegible]
1892	[illegible]	[illegible]	[illegible]	[illegible]	47,550	20,290	4,000	4,780	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46,200	19,160	4,000	[illegible]	[illegible]
1894	[illegible]	[illegible]	[illegible]	[illegible]	44,750	18,020	4,000	4,780	[illegible]
1895	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16,850	4,040	4,430	[illegible]
1896	[illegible]	[illegible]	[illegible]	[illegible]	46,295	20,205	2,670	4,180	[illegible]
1897	[illegible]	[illegible]	[illegible]	[illegible]	45,408	12,360	4,586	[2] 4,500	[illegible]
1898	134,277	[illegible]	[2] 45,000	10,537	23,941	19,857	[2] 3,000	[2] 4,000	269,216
1899	[illegible]	[illegible]	[illegible]	10,637	44,591	[illegible]	1,569	[2] 5,000	361,096
1900	[illegible]	[illegible]	[illegible]	10,541	[illegible]	[illegible]	[2] 3,000	[2] 6,000	[illegible]
1901	[illegible]	17,600	[2] 60,000	10,528	44,686	23,658	2,000	[illegible]	[illegible]
1902	[illegible]	[illegible]	[2] 30,000	11,067	14,519	5,155	1,302	[illegible]	[illegible]
1903	[illegible]	[illegible]	43,920	11,045	43,075	11,275	3,230	[2] 6,000	[illegible]
1904	126,234	14,412	[illegible]	6,739	16,141	5,479	3,531	[2] 4,000	[illegible]
1905	[illegible]	28,456	[illegible]	8,407	[2] 15,000	16,143	2,585	[2] 5,000	[illegible]
1906	[illegible]	[illegible]	[illegible]	16,655	16,180	20,116	1,555	[2] 5,000	413,441
1907	[illegible]	[illegible]	[illegible]	17,008	26,797	24,273	1,801	11,900	454,369
1908	[illegible]	38,485	[illegible]	16,800	25,338	14,175	1,532	[2] 5,000	[illegible]
1909	208,302	31,942	[illegible]	20,412	[4] 22,744	[illegible]	4,282	[illegible]	421,451
1910	248,097	[illegible]	93,412	35,910	20,281	[illegible]	5,397	[illegible]	[illegible]
1911	247,077	[illegible]	[illegible]	18,292	19,738	[illegible]	4,241	4,700	[illegible]
[illegible]	271,656	59,794	117,081	13,846	17,604	[illegible]	[illegible]	4,162	[illegible]
1913	251,752	[illegible]	97,951	15,226	18,936	28,499	5,452	[2] 10,000	[illegible]
1914	300,287	51,414	85,730	15,294	19,600	31,636	6,025	[illegible]	526,944
1915	[illegible]	[illegible]	88,365	12,627	26,011	30,932	4,244	20,060	513,361
[illegible]	304,271	55,140	[illegible]	12,945	[illegible]	27,920	4,132	12,535	[illegible]
1917	316,875	[illegible]	97,555	29,908	15,991	37,765	4,208	14,820	561,334
1918	225,446	40,140	[illegible]	10,516	22,151	26,575	2,146	11,776	435,790
1919	310,259	[illegible]	101,457	25,928	23,511	37,527	4,766	[illegible]	558,175
1920	329,561	41,387	[illegible]	13,799	21,810	37,222	7,604	16,401	567,544
1921	325,249	[illegible]	89,420	22,347	40,609	53,057	5,100	40,802	[illegible]
1922	342,148	[illegible]	[illegible]	17,904	21,035	35,127	6,740	24,349	588,769
1923	379,349	[illegible]	135,365	16,794	9,650	45,583	5,229	8,943	642,734
1924	337,767	[illegible]	136,840	31,987	22,278	[illegible]	8,195	17,539	615,178
1925	334,581	41,537	128,180	31,536	17,776	[illegible]	[illegible]	11,640	621,836
1926	356,904	[illegible]	117,038	32,423	[illegible]	50,320	[illegible]	11,707	653,564
1927	[illegible]	55,984	106,863	33,203	62,216	47,802	5,485	15,550	779,671
1928	370,098	61,146	103,390	33,811	63,866	49,067	7,546	14,211	703,135
1929	403,772	53,859	[illegible]	34,645	[illegible]	[illegible]	7,158	25,190	736,477
1930	426,340	[illegible]	[illegible]	35,589	34,245	44,682	[illegible]	28,871	722,393
1931	380,096	44,361	[illegible]	[illegible]	33,954	22,265	8,285	[illegible]	[illegible]
1932	412,984	57,297	87,104	30,886	47,116	[illegible]	5,752	33,730	705,787
1933	409,313	[illegible]	86,831	32,400	26,573	25,376	6,074	[illegible]	660,934
1934	378,494	38,737	92,477	30,686	26,946	[illegible]	[illegible]	[illegible]	638,766
1935	[illegible]	[illegible]	[illegible]	30,614	[illegible]	[illegible]	[illegible]	22,323	755,721
1936	90,127	[illegible]	[illegible]	33,139	[illegible]	[illegible]	[illegible]	22,435	663,014

[1] [illegible] Other unmarked quantities from biennial reports of State engineers of Colorado or from annual reports by division engineer for division 3 on file at Denver, Colo.

[illegible]

[2] Available records at State office show approximately 37,000 acres for district 20 in this year but are believed incomplete. The figure shown is an estimate based on general conditions applying in this year.

[illegible]

[illegible] may be balanced by an error the other way in another district.

Owing to the method adopted by stopping acreage when a decree stops * * * the acreage is sure to be large enough each year prior to about 1889, as a ditch very seldom waters its full amount of land the first year of its construction, while the supposition on which the acreage was handled does do this.

At an earlier place in his report (p. 57) Follett remarked as follows regarding the figures referred to in the foregoing quotation:

The State legislature of 1889 passed a bill, which became a law, instructing the State engineer to gather each year and embody in his biennial report statistics as to the amount of water used and land irrigated by each ditch in the State. It became the duty of the water commissioners to collect this information under instructions from the State engineer and superintendents of the several divisions. The work had to be paid for, however, by the counties, and prior to 1896 the county commissioners in several counties have refused to allow the bills of the water commissioners for this work. This has resulted in either no statistics being gathered in those counties, or in what were obtained being collected in a perfunctory way from the returns made by the owners or managers of the different ditches, without any attempt at eliminating errors and obtaining accurate results. This has been especially true in the third division, no agricultural returns whatever having been made from there until 1895, when partial reports were returned from districts 20, 21, 24, 25, 26, and 27. This year Mr. Anderson, the superintendent, made an heroic attempt to obtain accurate returns. He has succeeded fairly well, although there are still many apparent discrepancies in them.

My report on the use of water in Colorado is based on the returns for 1895 and 1896, supplemented by quite a voluminous correspondence, both by mail and wire, with Mr. Anderson and

[illegible]

other parties, and some information I collected in Denver, Alamosa, and Antonito. As before stated, it is to be regretted that more time was not spent in the valley in the personal gathering of data, as a few days of such work would have added very materially to the accuracy and consequent value of the report.

While most writers concerned with the history of the agricultural development of San Luis Valley have quoted Follett's irrigated acreage statistics for the years 1880 to 1896, it has by no means been the universal custom to quote his opinion of their reliability. This is not to say, however, that the accuracy of the commissioners' statistics for San Luis Valley, for the whole range of years since 1880, has been free from examination. For example, Tipton's analysis of various statistics (66), quoting Howard D. Sullivan, then (1924) deputy commissioner and statistician of the Colorado State Board of Immigration, says bluntly that "the water commissioners' figures are invariably much too high." The conclusion reached by Tipton was that "the final result (of the analysis) shows an approximate irrigated acreage in San Luis Valley of from 375,000 to 425,000 acres", for the 5-year period 1919 to 1923, although the commissioners' figures for that period ranged from 558,175 acres to 642,734 acres. An actual field survey of irrigated areas in the valley, made by Tipton in 1925–26 in an attempt to resolve definitely the doubts which occasioned his 1924 analysis, produced a total of 494,200 acres, or 80 percent of the 621,836 reported by the water commissioners for 1925. (See p. 329). Osgood's survey (table 27) showed 507,471 acres irrigated in 1927, while the commissioners' reports for that year showed 779,671 acres. The Bliss survey as of 1932 (table 27) showed 534,806 acres as compared with the commissioners' total of 705,787, while the Dallas survey as of 1934 (table 27) showed 428,737 acres as compared with 638,766 acres reported by the commissioners.

The lack of harmony between the commissioners' figures and those mentioned above, as well as others to be discussed in later paragraphs led the Bureau of Agricultural Engineering to write State Engineer Hinderlider, toward the close of the survey here reported, requesting him to describe the method by which the commissioners' figures were obtained and the way the work of canvassing has been paid for, together with such comment as he might care to make regarding the validity and reliability of the figures. Mr. Hinderlider's response was as follows:

Replying to your letter * * *, desiring to be advised of the method pursued in past years in collecting official data on irrigated and irrigable areas in the San Luis Valley, and the quantity of water diverted, will say that an act of the legislature in 1903 provides that the water commissioner shall keep reports which shall contain a statement of the actual carrying capacity and the amount of water actually carried by each ditch or canal in his district for each and every day when water is being carried, the total number of acres lying under each ditch or canal, and the number of acres actually irrigated therefrom; also a statement of the kind of crop and the acreage under each decreed ditch or canal, the amount of water stored in each reservoir, the amount used therefrom, with the dates of such storage and use; and such reports shall be on blanks, or in books prepared for that purpose and furnished by the State engineer. The law requires that such reports shall be subscribed and sworn to by the water commissioner, and filed in the office of the irrigation division engineer. It is customary also to file copy of such reports in the office of the State engineer.

Presumably, the reports of the water commissioners in the San Luis Valley, Colo., are compiled in conformity with the provisions of law. We all appreciate the fact, however, that, due to human frailties, and the fact that water commissioners in question are paid by the boards of county commissioners on a per diem basis, the time is limited in which to prepare such reports. Generally speaking, the amount irrigated in any one year under each ditch is obtained from the superintendent or secretary of the ditch company, or the individual water users under the smaller ditches. It is not customary for the water commissioner to make personal investigation to determine such acreages.

The results of a careful cruise of practically all of the irrigated lands in the Arkansas and South Platte River basins in this State a few years ago by this office disclosed that the amount of irrigated land, as shown by the water commissioners' reports, was somewhat high, and that the reports of the United States Bureau of the Census were somewhat low. It must be obvious why this would be true.

In the reports of the commissioner of water district no. 20 in the San Luis Valley, a considerable acreage is included as pasture land where water is intermittently applied as the same may be available in the river, for the protection of blue-stem pastures.

As you doubtless are aware, practically all of the larger irrigation canals in district 20, which is by far the largest district in the valley, have been equipped with automatic registers, and the amount of water diverted has been quite accurately determined.

Cruises of lands under the large Rio Grande canal, and the Empire canal, both diverting water from the Rio Grande River, were made by Mr. Tipton in 1931 and 1932. It is my understanding that you have copies of that report, which could be compared with records of the water commissioners, of lands irrigated under the same canals for the same year, from which it could be ascertained what variance, if any, exists between the commissioner's report and the cruise made by Mr. Tipton.

Acreage Statistics Compared

Also involved in the 1924 analysis by Tipton were the statistics assembled by the United States Bureau of Agricultural Economics in cooperation with the Division of Agricultural Statistics (then a part of the Colorado State Board of Immigration, but now in the Colorado State Planning Commission). The pertinent figures are those of cropped and irrigated acreage reported, by counties, by the county assessors. A discrepancy is involved in comparing these (and Federal farm census) figures with those representing the Colorado portion of San Luis Valley as a unit for the reason that parts of Hinsdale, Mineral, and Saguache Counties are outside the San Luis Basin; but as these outside parts are of relatively small

agricultural importance, such a comparison is not [illegible] affected by them.

Ignoring this difference in boundaries, therefore, table 2 shows for 1924, 1929, and 1934, the irrigated acreages in San Luis Valley as reported by the water commissioners, the Colorado Cooperative Crop Reporting Service, and the Federal census.

Aside from illustrating the wide discrepancies between the data from the three sources, table 2 appears to be in line with the conclusion stated in Mr. Hinderlider's letter above quoted with reference to the Arkansas and South Platte Basins, that "the amount of irrigated land, as shown by the water commissioners' reports, was somewhat high, and that the report of the United States Bureau of the Census was somewhat low." However, it is not obvious why this must be true.

TABLE 2.—*Area irrigated, San Luis Valley, Colo., by specified years*

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[6] 341,856	[illegible]
[illegible]		[7] 627,391	
[illegible]	[illegible]	[9] 388,758	[illegible]

[illegible]

[6] Not including pasture.

[7] [illegible] receiving water

[8] All harvested crops, not including pasture, but including 195,648 acres of "hay crops."

[9] Irrigated crops harvested, not including irrigated pasture nor areas of crop failure [illegible]

[10] "Irrigated land from which crops were harvested"; hence does not include irrigated pasture nor areas of crop failure and idle or fallow land.

The agreement between the figures compiled by the Colorado Cooperative Crop Reporting Service and those resulting from the Federal farm censuses is much closer than that between the commissioners' totals and either of the other two compilations; but the lack of harmony between the 1929 Federal irrigation census figure and the 1929 farm census total needs explanation. It is perhaps sufficient to say (after noting that the discrepancy is somewhat mitigated by the inclusion in the irrigation census figure of a large but unspecified acreage of pasture, etc.) that the Federal irrigation census obtains its San Luis Valley acreage data from essentially the same sources as those which contribute to the commissioners' compilations, while the Federal farm census is conducted independently of the other canvass as far as large enterprises are concerned, being, in fact, a farm-to-farm rather than an enterprise-to-enterprise enumeration.

[illegible] went into a comparison similar to that now attempted. A portion of the summary by Mr. Sullivan, there reproduced, is pertinent here and [illegible]

1. The United States census report of "cropped acreage" is fairly accurate, except that it is consistently low. This is due to some farms having been missed by the census taker. This is easily accounted for, as the census taker gets 33 cents per schedule, and in a sparsely settled country, as the Valley, some isolated farms would naturally be overlooked. A questionnaire was sent by the Board of Immigration to 1,500 farmers distributed over the State. One question that was asked was whether or not the farmer had been visited by the United States census taker. The result showed that from 5 to 8 percent had not been visited.

2. The water commissioners' figures are invariably much too [illegible]

3. The county assessors' reports are considered fairly accurate for all crops except native hay and alfalfa. For these two crops the figures are very low. This is due to two causes. First, at the time the assessor makes his canvass in the spring, the farmer does not know how many acres of hay he is going to cut, as this depends on the water supply for that year. Second, at the time the State board of immigration began its investigations, the farmer was asked how many acres of each crop he intended to plant that particular year. As alfalfa and native hay are perennial crops, in some cases they may not have been reported and a false return acquired in this way. This query has been changed and now the farmer is asked how many acres of each crop he intends to harvest.

In general, the reports from the county assessors are improving all the time, but the error in the report on forage for the 5-year period being investigated is fairly consistent.

4. In both the census report and the county assessor's report on "cropped acreage", there is no allowance made for the item of "irrigated pasture." An arbitrary figure of 50,000 acres for the Valley for this item is conservative.

The foregoing perhaps needs no comment except as regards the matter of completeness in the Federal farm census. In brief, the fact that a farm operator is not interviewed by a census taker is no proof that the census does not include his farm. In cases where the farm operators cannot be found, the best reports available from other sources are obtained. The following quotation from the Instructions to Enumerators issued by the Bureau of the Census to the enumerators employed in the 1930 census is illustrative of the long-standing practice:

> Obtain information with regard to a farm from the farm operator in every case where this is possible. If it is necessary to accept the statements of a member of his family, or of some other person, be sure that this person is able to give you reliable information.
>
> When you find a farm whose operator lives outside your district, or who with his family is outside the district at the time of enumeration, so that it is not possible for you to see him or his family personally, secure the information for this farm as best you may from a neighbor or from any other reliable source that may be available, and note at the top of the schedule that it was so obtained. It is essential that you turn in a completed schedule for *every farm in your district.*

In addressing the Denver office of the Bureau of Agricultural Economics to obtain copies of the publications from which the statistics in the second line of table 2 were abstracted, the Bureau of Agricultural Engineering wrote that Federal census reports were not involved in the request, as they were already available. In reply,

F. K. Reed, agricultural statistician, wrote in part as follows:

> It is noted that you want this information for a selected group of counties in what we call the San Luis Valley located in south central Colorado. Also, that you mention having access to tabulations of the Federal Bureau of the Census for the 3 census years. I might point out that I view these data as carried in the publications enclosed as being less reliable than those given in the Federal census publications. This is particularly true for the San Luis Valley counties where it has always been very difficult to get satisfactory enumerations through our assessors. Hence, if you plan to use the information given in the enclosed bulletins to get some measure of true agricultural production in those counties for the years in question or a measure of the amount of land available for potential agricultural production, I might suggest that the data mentioned above be given due consideration.

Mr. Reed's favorable implication regarding the Federal farm census figures, taken with Mr. Hinderlider's comments relative to the commissioners' data, appears in a detailing of the Valley's agricultural history to justify some further attention to the census statistics by themselves as well as in comparison with the figures obtained by the other agencies, although the farm censuses were taken only at decennial periods until 1925, and only at 5-year intervals since then.

In such an examination, some results of which appear in table 2, the discrepancies in total acreage figures are fully as disconcertingly matched by wide differences in the figures reported elsewhere for specified crops. The important potato crop provides a good example. The Cooperative Crop Reporting Service reported 33,410 acres in potatoes in 1929, the Federal census reported 37,243 acres, and the water commissioners reported 40,027. In 1934 the differences were wider, the corresponding figures being 30,760 acres, 43,078 acres, and 53,483 acres. In the case of the large acreage in hay crops (including legumes "saved for hay") the 1934 figures were, respectively, 227,620 acres, 168,990 acres, and 310,493 acres.

No figures on irrigated pasture appear in the reports of the Cooperative Crop Reporting Service. The census has reported a variety of figures on pasture since 1924 (plowable pasture, woodland pasture, and other pasture), of which those descriptive of "plowable pasture" might appear to have significance as applying to San Luis Valley (50,499 acres in 1924, 72,555 acres in 1929, 30,842 acres in 1934) if the definition permitted.[3] The water commissioners reported 153,980 acres of irrigated pasture in 1929 and 150,000 acres in 1934. There is, in fact, basis for much confusion over this item, as was discovered in the vegetative-cover mapping which formed an essential portion of the investigation here reported. Regarding both hay land and pasture land, even more pointedly than in the case of land raising the other crops, the question of sufficiency of the practiced irrigation may serve to raise puzzling doubts as to just what "irrigation" shall be understood to mean. For example, Mr. Hinderlider noted (page 301) with specific reference to water district no. 20, that a "considerable acreage is included as pasture land, where water is intermittently applied as the same may be available in the river." How this matter was handled in the 1936 mapping is discussed in the chapter headed "Vegetative cover survey."

No statistics pertinent to San Luis Valley appear in the reports of the 1850 and 1860 Federal censuses. The 1870 census showed for the (then) counties of Conejos, Costilla, and Saguache a total area of "improved land" in farms of only 12,797 acres, with no segregation into crop acreages but with production figures indicative of small crops of grain, alfalfa, and potatoes. Ten years later (1880 census) the following totals were reported for the (then) counties of Conejos, Costilla, Rio Grande, and Saguache:

	Acres
Total improved	67, 125
Tilled, including fallow and grass in rotation, whether pasture or meadow	39, 933
Permanent meadows, permanent pastures, orchards, and vineyards	27, 192

Follett's San Luis Valley figure for 1880 was 131,475 acres irrigated. (See table 1.)

The Bureau of the Census conducted its first irrigation canvass in 1890. For the crop year then reported (1889), 1,037 irrigated farms (number of irrigators) were enumerated. The total acreage of the irrigated farms was shown as 413,726 acres, of which 147,830 acres was irrigated. This irrigated acreage was accounted for only to the following extent: Cereals, 27,456 acres; alfalfa, 1,089 acres. (Follett's 1889 figure for San Luis Valley was 285,310 acres. See table 1.)

The 1890 census reported 168,000 acres as "improved" in the counties then including San Luis Valley.

The 1889 census total for the irrigated area in the San Luis Valley counties was somewhat lower than the total shown in the Report on Irrigation by the Office of Irrigation Inquiry, United States Department of Agriculture, published in 1893 as Senate Executive Document No. 41, Fifty-second Congress, first session. As of (apparently) 1891, 275,760 acres was reported as "cultivated" by the four major ditch companies then operating and by "small farmers" (p. 154); but in the same document (p. 156) R. C. Nisbet, of Pueblo County, estimated the "area under cultivation" in Conejos, Costilla, Rio Grande, and Saguache Counties as only 100,000 acres, although he also estimated that 2,000,000 acres was under ditch. The Report of the Special Committee of the United States Senate on the Irrigation and Reclamation of Arid Lands (75) had shown the following figures representing the Rio Grande drainage area

[3] Land used only for pasture or grazing in 1924 which could be plowed and used for crops without clearing, draining or irrigating.

TABLE 3.—*Areas of specified crops grown in San Luis Valley, Colo., 1902–35 (except 1903, 1904, and 1919), as reported by water district commissioners*

[illegible]

Year	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] peas	Potatoes	Sugar [illegible]	[illegible]	Field peas	Beans	[illegible]	[illegible] carrots	[illegible]	Other crops	Summer [illegible]	Total irrigated
[illegible]	[illegible]	226, 931	957, 81	[illegible]	8, 873	48, 792	2, 174	1, 508	80, 876	2, 595		[illegible]	2, 066	[illegible]		[illegible]
[illegible]	64, 025	178, 187	77, 272	150, 432	9, 747	53, 483	1, 510	2, 032	48, 607	1, 613		532	18, 061	33, 270		[illegible]
[illegible]	54, 246	119, 980	59, 938	67, 061	7, 179	25, 339		327	27, 514	2, 229			9, 183	18, 967		[illegible]
[illegible]	[illegible]	[illegible]	97, 832	155, 506	13, 448	67, 515	[illegible]	2, 280	52, 961	2, 150	1, 863	313	16, 773	21, 218		[illegible]
[illegible]	97, 822	324, 828	73, 582		8, 902	57, 356	1, 581	1, 581	60, 717	1, 555	[illegible]	147	[illegible]	7, 897		[illegible]
[illegible]	[illegible]	337, 846	113, 502		5, 827	45, 665	396	3, 664	68, 376	1, 283	851	87	28, 810	30, 802		[illegible]
[illegible]	83, 261	233, 627	84, 107	144, 899	9, 320	40, 027		4, 031	67, 997	892	1, 250	[illegible]		45, 136	[illegible]	736, 477
[illegible]	86, 331	[illegible]	89, 613		[illegible]	39, 328	[illegible]	3, 294	80, 694			57		[illegible]		703, 135
[illegible]	[illegible]	225, 017	92, 323		3, 319	44, 558		4, 837	82, 695	[illegible]		79	[illegible]	202, 729		[illegible]
[illegible]	91, 091	341, 398	90, 022		4, 617	28, 487	[illegible]	4, 226	73, 278	1, 782			27, 922	11, 009	8, 921	683, 564
1925	85, 547	290, 358	92, 539		2, 411	23, 353	1, 471	[illegible]	78, 377	2, 325	118	134		41, 171		621, 836
[illegible]	81, 233	275, 868	87, 390		755	[illegible]	123	[illegible]	86, 058	1, 998		59	[illegible]	[illegible]		[illegible]
[illegible]	79, 201	322, 789	91, 611		905	35, 668		636	85, 375	2, 991		63	[illegible]	[illegible]		642, 734
[illegible]	69, 373	[illegible]	84, 252		913	46, 448			76, 811			[illegible]		76, 633		588, 768
[illegible]	72, 629	182, 270	128, 900		701	35, 636			75, 089			63		[illegible]		[illegible]
[illegible]	60, 718	[illegible]	97, 010		649	28, 023			68, 115	1, 295		112		34, 849		[illegible]
[illegible]	47, 227	166, 126	81, 572		1, 117	24, 276			90, 796			108		[illegible]		[illegible]
1917	55, 498	207, 398	114, 484		1, 386	17, 773			104, 834			73		[illegible]		[illegible]
1916	[illegible]	[illegible]	118, 136		471	12, 086			88, 515			84		[illegible]		536, 921
1915	41, 976	[illegible]	[illegible]		[illegible]	9, 702	37		[illegible]			[illegible]		[illegible]		513, 361
1914	34, 160	229, 227	162, 627	36, 062	381	9, 802	[illegible]		37, 789			[illegible]		[illegible]		510, 016
[illegible]	29, 122	227, 321	130, 099		[illegible]	11, 808	3, 069		78, 145			39				378, 825
[illegible]	31, 227	224, 740	186, 243		492	13, 875	7, 307		49, 160			40		[illegible]		519, 789
1911	2, 521	198, 935	151, 325		[illegible]	[illegible]	5, 449		74, 128			51				468, 998
[illegible]	18, 189	[illegible]	209, 736		400	14, 625	393		36, 633			[illegible]				465, 462
[illegible]	16, 909	[illegible]	177, 956		142	11, 251	[illegible]		25, 136			49				[illegible]
[illegible]	13, 661	190, 298	[illegible]		[illegible]	[illegible]	10		85, 024			43				439, 239
[illegible]	[illegible]	212, 215	100, 110		827	5, 105			[illegible]			[illegible]				454, 369
[illegible]	[illegible]	134, 885	118, 968		189	7, 440			147, 013			[illegible]				420, 341
[illegible]	8, 000	[illegible]							40, 000			[illegible]		170, 000		318, 100
1902	[illegible]	[illegible]	39, 135			[illegible]	795					[illegible]		12, 537		157, 547

in Colorado, apparently for 1889: under ditch, 596,097 acres; actually irrigated, 250,263 acres.

The 1900 Federal irrigation census reported as the "acreage irrigated from streams" in 1899, for the third water division, 295,988 acres. For the entire State of Colorado, 7,058 acres was reported as irrigated from flowing wells, almost all of which was undoubtedly in San Luis Valley. (Water commissioners' total, 361,097 acres. See table 1.) The Census total for "improved" land in all farms was 381,062 acres.

A special census of irrigation taken by the Bureau of the Census in 1902, enumerated as irrigated from Rio Grande and tributaries, 1,819 farms and 303,985 acres. (Water commissioners' total was 187,551 acres. Commissioners' totals for 1900 and 1901 were 412,829 and 426,472. Severe drought was cited as the reason for the decline in 1902. See table 1.)

The 1910 irrigation census (for 1909) reported as irrigated in the Rio Grande drainage basin 460,781 acres. The 1920 irrigation census (for 1919) reported the total as 608,924 acres—both higher figures than the commissioners reported. The census total for improved land in all farms in 1910 was 588,905 acres. The corresponding 1920 total was 499,668 acres.

Whatever the uncertainties created by such comparisons as those set out in the preceding paragraphs, they should be resolved so far as the present situation is concerned by the tabulations resulting from the 1936 vegetative cover mapping (table A).[4]

The general crop history of San Luis Valley may be traced clearly enough for the present merely informative purpose, from table 3. (Discrepancies in the totals shown in tables 1 and 3 are not considered serious enough, in this comparison, to require explanation or adjustment.)

Drainage, Storage, and Allied Problems

San Luis Valley's rapid agricultural development in the 1880's and 1890's, influenced by a lack of sufficient storage, the widespread practice of "subirrigation" (see p. 317), and the uncontrolled flow of many artesian wells, early combined to bring about a serious condition calling for extensive drainage. The following paragraphs[5] concisely describe this condition (with particular reference to the closed area) and further explain some of the circumstances producing it:

> On casual inspection, the entire valley seems to slope very gently and drain into the Rio Grande, which enters the basin almost due west of Alamosa and turns south at the city toward the New Mexico line. However, as a matter of fact, an imperceptible low divide in the valley floor parallels the north side of the Rio Grande, at a distance of 2 to 5 miles, from the point where it enters the basin near the town of Monte Vista southeastward to a point below Alamosa. This divide converts the northern part of the valley into a basin that is "closed" so far as natural drainage is concerned.
>
> Within this closed area such of the waters of the local streams and of the diversions from the Rio Grande as are not consumed in irrigation and by natural growth or by evaporation, finally find their way into a low trough parallel to the foot of the eastern range. There, in seasons of abundant run-off, the waste waters collect in numerous small lakes, swamps, and low waterlogged areas. In seasons of moderate run-off the areas of free-water surface and swamp are greatly diminished. After a series of dry years, San Luis and Head Lakes constitute the only free-

[4] [illegible]

[5] From 1935 report by Stout, Fowler, and Dobler (59).

water surface. The water table throughout the trough is ordinarily relatively high.

* * * * *

The history of the development is interesting. The first area irrigated was along the Alamosa-Salida railroad line, in the lower part of the trough immediately west of and parallel to the natural seeped area. In this section of the basin a broad belt of land was rapidly brought under irrigation. Drainage difficulties soon developed that led to progressive abandonment of lands along the eastern border of this irrigated zone and to its progressive extension westward. As years went by, this progressive shifting of the irrigated zone westward continued until its western margin had reached the extreme west side of the valley and the broad stretch of once-occupied lands to the eastward was left to revert to its original state, badly damaged, however, by alkali.

Drainage of the western area then became necessary, and the waters developed thereby aided in a progressive reoccupation of a part of the neighboring lands to the eastward that were once occupied and then abandoned on account of becoming water-logged and affected by alkali.

* * * The growing demand for water has led to the re-use of the drainage return from the higher areas to the westward, unless limited in some way. As matters now stand, drain waters are reapplied with no return therefrom during the irrigation season. In ordinary years, waters are so used only in the period from April to October, but in years of subnormal rainfall and run-off, such irrigation is extended throughout the winter. Little water has issued from any of the drains into the sump area in the past 6 or 7 years.

It appears certain that this re-use of drainage water will be extended and continued, and additional lands brought back into use east of present occupied territory until the area consumes practically all the natural and return supply.

Throughout its modern history the Valley has been notable for its great number of artesian wells. The 1936 investigation by the Geological Survey disclosed that the number of these wells, including pumped and flowing, urban and rural, was 6,074. The total estimated annual discharge was 118,945 acre-feet. There were also a large number of artesian springs of estimated annual discharge totalling 47,450 acre-feet.

As of January 1, 1930, the Federal irrigation census reported that 614 of the flowing wells were used for irrigation, the remainder being domestic and stock-watering wells. In general, the irrigation wells are the larger, the average capacity of those enumerated in 1930 being 62½ gallons per minute.

Since all but seven of the flowing wells reported for Colorado were in San Luis Valley, practically all (say 3,600 acres, or about 6 acres per well) of the total acreage (3,786 acres) was Valley land. Most of the irrigation wells—542 of the 1930 total—are in the "live" area of the Valley, the remaining 72 being in the portion tributary to Saguache and San Luis Creeks (Pl. 11.)

The 1930 census reported only one pumped well used for irrigation, but there are now many more, the growth of this phase of irrigation supply having been one of the most notable developments of the last few years. It is still continuing, the section around Center having experienced a marked activity in the establishment of new pumping plants during the past year. According to the United States Geological Survey, there are now 160 pumped irrigation wells in the area east of the Rio Grande canal and north of the river. Forty-six of these wells were installed in 1936.

Practically no control of the discharge of many of the flowing wells (domestic and stock as well as irrigation) has been exercised. Notwithstanding the small acreage (mostly farm gardens and pastures) which is watered from this source, this lack of curb has contributed to the raising of the water table in some portions of the Valley, so having been a factor in creating the need for drainage.

Conkling describes 1919 conditions as affected by the water table in the following (selected) paragraphs (12):

The geological formation is such that an artesian basin exists under the valley floor * * *. This basin is fed by creeks and rivers flowing across the outwash as they leave the mountains and possibly by percolation in the mountains themselves, although it seems improbable that any large contribution occurs from this source. The calculated head of the flowing wells defines the altitude of the impermeable stratum which forms the top of the aquifers and as some of the larger canals divert above this altitude and above the point in the stream where measurements have shown seepage losses to occur, it is probable that the loss from canals is contributing to some extent to the basin, and in succeeding calculations some estimates are made of this quantity.

* * * Siebenthal gives the number of artesian wells as 3,234 with an average discharge of 40 gallons per minute.

* * * The wells are, in general cased to the first clay bed which appears to be the upper confining layer of the artesian basin; hence capping successfully conserves the water for use elsewhere and shuts off the contribution to ground-water.

* * * It was * * * found that the artesian basin had extended westward in the neighborhood of Center since Siebenthal's time. (Pl. 5.) The maximum extension is about 2 miles and gradually diminishes from this distance to nothing near Saguache and Monte Vista. The only way of accounting for this is contribution to the basin which did not exist before irrigation began. If this is correct, when the basin finally reaches a state of equilibrium, there may be more outflow from the valley than is hereinafter estimated.

There are said to be 850,000 acres of seeped land in the valley. This is hardly true. There are 850,000 acres * * * under which the water table lies 8 feet or less of the surface. With the coarse subsoils of part of the valley, this water table hardly affects the surface on a part of the valley and it can be successfully farmed. The area east of the north and south line 3 miles west of Mosca is in mind. At Mosca the water table is about 4 or 5 feet below the surface and about 6 miles east of Alamosa about 8 feet. It can be said with truth that there are 850,000 acres which should be seeped if more of the land were irrigated.

* * * there are areas unaffected by ground-water on the outwash slopes of the Conejos, Alamosa, Rio Grande, and Saguache Rivers totaling 200,000 acres, giving a total, in addition to the small areas along the Sangre de Cristo Range, of 1,050,000 which are near the larger streams, are largely under ditches diverting from them or will have ground-water very close to the surface with the best possible system of drainage.

* * * It is evident that much more land can be irrigated than at present. Such extension depends largely on ability to control the discharge by reservoirs.

For the entire Valley the 1930 census reported 25 reservoirs used for irrigation storage, with total capacity of 281,994 acre-feet (of which less than one-third was on Rio Grande, Conejos, and Alamosa Rivers). These figures are not in agreement with statistics obtained by the Bureau of Agricultural Engineering in 1936, when 15 reservoirs alone were represented as having total capacity of 312,625 acre-feet. In addition to the 15 mentioned, each of which had a capacity of more than 1,000 acre-feet, a number of small storages were listed. Some of these were not irrigation reservoirs; however, the discrepancy in acre-foot totals is explainable by the excessive capacity of some of the reservoirs relative to the amounts of water retained in any but exceptional years.

Notable is the fact that, with one exception, all the major storages were created since 1900—that is, after drainage needs had already become serious; but as illustrated by Tipton (69) in table 4 (for the lands between Alamosa and Del Norte), the spring flow is still utilized to an extent considerably in excess of the ideal demand.

TABLE 4.—*Assumed ideal irrigation demand (600,000 acre-feet) on Rio Grande between Alamosa and Del Norte, Colo. (after Tipton)*

Month	Assumed ideal demand acre-feet	Percent total seasonal	Actual diversion, percent total seasonal
April	30,000	[illegible]	[illegible]
May	[illegible]	17	[illegible]
June	162,000	27	31
July	156,000	26	16
August	108,000	18	12
September	30,000	5	[illegible]
October	12,000	2	[illegible]
Total	600,000	100	100

[illegible] from which table was adopted. Corrected, made arbitrarily by Bureau of Agricultural Engineering to produce total of 100.

The existing storage is locally asserted to have been effective in improving irrigation use,[6] but as is the case elsewhere in Upper Rio Grande Basin as well as in many other irrigated valleys of the West, the need for extensive drainage persists, although it is obvious from table 5 that the existing drains have been effective in protecting a large area which without them would now be partly, if not wholly unproductive.

TABLE 5.—*Land in drainage enterprises, its condition and use, San Luis Valley, Colo., 1930*

[Assembled from the more elaborate tabulations for Alamosa, Conejos, Rio Grande and Saguache counties in the reports of the Federal drainage census of 1930]

[In acres]

Land in organized drainage enterprises	168,946
Land in occupied farms	118,133
Improved land	117,553
Land in planted crops	107,543
Land idle	55,053
Land unfit to raise any crop	2,428
Land unfit to raise any crop prior to drainage	90,342
Land fit to raise crops (partial and normal)	166,518
Land fit to raise crops prior to drainage	78,604

Middle Valley

The several available sources of statistical information relative to the irrigation development of the main and tributary valley areas between the Colorado State line and San Marcial are the Follett report of 1896, Federal census compilations, and certain surveys made by the State of New Mexico.

As in the case of his San Luis Valley tabulations, Follett's figures (20) were accompanied by certain reservations.[7] In the New Mexico investigation, he did not have a basis for estimates equivalent to the more or less unsatisfactory water commissioner records he found in Colorado. Accordingly, the figures he finally reported were largely the product of a canvass he conducted personally.[8]

Follett's tabulations covered the years 1880 to 1896, and were made according to "water districts "of his own creation. The boundaries of these districts were such as to permit combinations of figures applicable to the

[6] In a personal communication to Mr. Stafford, Mr. Tipton writes that "on the Rio Grande proper there is [illegible] acre-feet of effective storage [illegible] * * * this storage is used to the limit in an attempt to reduce the distorted method of using water between Del Norte and Alamosa. 50,000 acre-feet of the effective storage is owned by the San Luis Valley Irrigation District, commonly known as the Farmers' Union. * * * the use of water by this system is almost identical with the assumed ideal (shown in table 4) * * * While the Farmers' Union system has sufficient direct flow decrees to permit large spring diversions, yet such diversions are not made. Before the construction of the Farmers' Union reservoir the diversions by the Farmers' Union canal were distorted in the same manner as the majority of the diversions along the stream between Del Norte and Alamosa.

"There is no question but what if substantial storage were provided on the stream the high spring diversions would be reduced and the late summer diversions would be increased by the release of the reservoir water * * *" (See also p. 329).

Also with reference to the effect of present storage, Mr. Hinderlider in a letter to Mr. McLaughlin writes that "for the 22-year period, 1915-36, the amount of water used from reservoirs by canals diverting in district 20 averaged 49,100 acre-feet per year and 34,000 acre-feet of this amount was used by one system—the Farmers' Union. The total acreage irrigated in district 20 is about 280,000 acres of which amount the Farmers' Union irrigates about 46,000 acres. Therefore, an average of 34,000 acre-feet of the stored water was used on an acreage representing about 16.5 percent of the total acreage irrigated in district 20.

"An analysis of the use of the water by the Farmers' Union indicates that the seasonal distribution for the diversions by the Farmers' Union approaches the seasonal ideal distribution (as set up in table 4, above).

"For the period 1928-35 the mean annual diversion by canals in district 20 was 538,300 acre-feet. 53,400 acre-feet of this quantity was diverted by the Farmers' Union canal, leaving 484,900 acre-feet as the aggregate diversions of the remaining canals in district 20. About 30,000 acre-feet of the 53,400 acre-feet diverted by Farmers' Union diversions, was reservoir water; and about 17,100 acre-feet of the balance of 484,900 acre-feet diversions, was reservoir water. In other words, an average of 56 percent of the total diversion by the Farmers' Union was stored water, while the stored water [illegible] * * *

"Available reservoir water has resulted in a material change in the seasonal distribution of the diversions of the Farmers' Union canal. For the years 1925 to 1928 inclusive (for which period the data has been determined) the Farmers' Union in the month of May diverted on an average only 60 percent of the water available to it under its decrees, the maximum for any May being 80 percent and the minimum being 46 percent. During the months of June for the above period an average of only 89 percent of the water available to it under its decrees was diverted by the Farmers' Union. The reservoir water available to the other systems on the river being only about 3.5 percent of the total diversion by those systems, is too small to change materially the distorted seasonal use."

[7] In considering the information relating to New Mexico the method of obtaining it must be borne in mind and due allowance made for its probable error. I believe that the total area of irrigated land given for each district is within 15 percent, and possibly within 10 percent, of the area actually watered an average year. (P. 74.)

[8] A part of the commissioners along the Rio Grande ditches were able to give me [illegible] it was difficult to learn the areas watered. Whatever land I saw I estimated as well [illegible] (P. 74.)

investigation here reported. Such a segregation appears in table 6.

TABLE 6.—*Areas irrigated in Rio Grande drainage basin of New Mexico from Colorado State line to San Marcial, as reported by Follett (20)*

[In acres]

Year	State line to White Rock Canyon	White Rock Canyon to San Marcial	State line to San Marcial
Prior to 1880	111,410	34,370	[illegible]
1880	113,360	32,470	[illegible]
1881	113,370	31,700	[illegible]
1882	113,460	31,700	[illegible]
1883	113,450	31,700	[illegible]
1884	113,850	31,700	[illegible]
1885	113,650	31,700	[illegible]
1886	114,670	31,700	[illegible]
1887	114,970	31,700	[illegible]
1888	115,050	31,700	[illegible]
1889	115,130	31,700	[illegible]
1890	116,380	31,700	[illegible]
1891	117,080	31,700	[illegible]
1892	117,680	31,700	[illegible]
1893	118,400	31,700	[illegible]
1894	118,440	31,700	[illegible]
1895	119,980	31,700	151,680
1896	118,330	31,700	150,030

Table 7 is a compilation by Hedke (27), assertedly based on the Follett surveys, a survey made by H. W. Yeo in 1910, and a drainage investigation conducted by the State of New Mexico in 1918. The discrepancy between the 1896 figure (31,700 acres) shown in table 6 and the figure for "acres under development" (50,000) appearing in table 7, both attributed to Follett, Hedke explains as follows: "Follett says, 'Their (the figures') probable error ranges from 10 to 20 percent for the areas watered', etc. Since the above figure of 31,700 acres, for the area watered in the Middle Rio Grande Valley was based on estimates and testimony obtained from those who could only use an estimate of the total areas under the ditches or previously irrigated as the basis for comparison, the error of 10 to 20 percent on the net area could easily involve the further error of 10 to 20 percent on the gross area, which together would readily extend his figure to 50,000 acres, and such is assumed . . ."

A fault in this reasoning appears to lie in the evident assumption that Follett's admitted possible error lay entirely and consistently in the direction of deficiency. Hedke's previous comment that "the data (Follett's) were secured from interviews and only purports to give the area farmed for that year, 1896, and in no way covers previously irrigated areas nor the areas under the ditch developments" is likewise not clearly supported by the descriptions of his "districts" recited by Follett.[9]

TABLE 7.—*Progress of irrigation development in the Middle Rio Grande Valley, [illegible] Follett, engineer for International Boundary Commission (20), H. W. Yeo, engineer, United States Bureau of Reclamation, and 1918 drainage survey by State of New Mexico*

Time, up to—	Number [illegible]	Second-feet capacity	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	537	25,555	—	Indian development.
1700	[illegible]	[illegible]	73,580	—	[illegible]
1800	70	1,808	100,380		[illegible]
[illegible]	80	2,099	123,315		[illegible]
[illegible]	82	2,145	124,800		[illegible] pleted developments.
[illegible]	71	[illegible]	[illegible]	74,800	[illegible] supply competition and rail- [illegible]
[illegible]	79	2,121	[illegible]	79,580	Further shortage and further rising water table.
[illegible]	[illegible]	1,957	47,000	77,800	War period.
[illegible]	60	1,850	40,000	84,800	Estimated present condition.

[1] Deduced from W. W. Follett's report (see table 6).

Hedke ends his analysis of the early figures in table 7 with the remark that "the size and capacity of the ditches, even as existing in 1910, confirm the conclusion that the entire area was in cultivation at one time, and not so far distant, as the ditches had not deteriorated to the requirements of the then cultivated areas." Yeo appears to have had a similar opinion, yet such a conclusion was not reached by Follett, notwithstanding his observation of areas previously irrigated and the excessive capacities of ditches. Indeed, modern practice in most irrigated sections, including Rio Grande Valley, scarcely justifies the broad assumption that areas have been watered in the past to the full extent of the carrying capacities of their canals. Follett's notes regarding the more or less migratory nature of the agriculture along the river, as forced by the deterioration of the land, seem to provide the more likely explanation of the evidences of prior extensive cultivation, although he himself was outspoken in commenting on the effects upon lower irrigators of the rapid developments in San Luis Valley.

While the early farm statistics of the United States census were obtained under much difficulty, they are of interest in the present discussion. No irrigation statistics were collected until 1890; but the 1850 census enumerated only 166,201 acres of "improved" land in the entire territory, distributed among the then counties as follows: Bernalillo, 13,436; Rio Arriba, 30,417; Santa Ana, 3,197; Santa Fe, 19,081; San Miguel, 42,880; Taos, 10,469; Valencia, 46,721.

[9] District no. 13, upper Albuquerque. The Mexicans, or Spaniards, settled on the vacant land in this district from 100 to 300 years ago. While the arable land probably amounts to over 40,000 acres, only about 8,000 is under cultivation. Much of the balance has been tilled at some time in the past; but as the land lies nearly level, and so has little natural drainage, as mentioned above, the lavish use of water has filled it with alkali and much of it has been abandoned, the owners simply moving back onto a little higher ground. I could see nothing, however, to lead me to the belief that the total acreage had raised materially in the past 15 years.

District no. 14, lower Albuquerque. While there is fully 75,000 acres of arable land in the district, less than one-fourth of this amount is cultivated. Much formerly watered has been abandoned and is now marsh land, white with alkali.

In this district and in district no. 15 evidence exists of there having been more land under cultivation at one time than is now tilled. I am satisfied that the shrinkage in these two districts is fully 10 percent, the larger proportion of it being in district no. 15. I was told that this contraction of area occurred about 1880. * * * I have therefore added to district 14 about 1,500 acres prior to 1880 and about 500 acres for 1880.

District no. 15, Socorro. There is probably not more than 20,000 acres of arable land in the whole distance of 50 miles from the mouth of the Puerco to San Marcial, and of this less than 6,000 acres is tilled. The evidence of the shrinkage in the area cultivated was here plain, and I therefore added to the 1894 acreage 1,200 prior to 1880, and enough to make a total of 6,000 acres in 1880.

[illegible] reported, distributed by counties as follows: Arizona, [illegible] Mora, 3,243; Rio Arriba, 28,077; Santa Ana, 4,947; Santa Fe, 13,266; San Miguel, 21,550; Socorro, 7,175; Taos, 9,777; Valencia, 22,344. (Pl. 1)

The corresponding county distribution for 1870 was as follows, the total being 143,007 (improved) acres: Bernalillo, 4,966; Colfax, 2,817; Dona Ana, 17,184; Lincoln, 9,887; Mora, 20,503; Rio Arriba, 6,721; San Miguel, 20,541; Santa Ana, 1,534; Santa Fe, 10,925; Socorro, 4,655; Taos, 33,686; Valencia, 9,588.

The 1880 census figures were slightly more detailed than those just quoted, as shown in table 8.

TABLE 8.—*Statistics of agriculture for New Mexico, as reported by the 1880 Federal census*

[In acres]

County	Improved	Tilled, including fallow and grass in rotation whether [illegible]	[illegible] meadows, [illegible]
[illegible]	3,821	3,642	[illegible]
[illegible]	[illegible]	[illegible]	14,038
Dona Ana	[illegible]	24,246	1,540
Grant	[illegible]	4,575	[illegible]
Lincoln	[illegible]	4,662	159
[illegible]	[illegible]	14,700	4,148
[illegible]	[illegible]	17,097	[illegible]
[illegible]	[illegible]	[illegible]	7,810
[illegible]	8,619	3,800	4,819
Socorro	26,013	17,802	8,211
[illegible]	33,740	32,901	839
Valencia	12,248	9,722	2,526
[illegible]	237,392	[illegible]	46,626

Thus, assuming that the then counties of Bernalillo, Socorro, and Valencia included the lands in the middle portion of the Rio Grande Valley now under consideration, but remembering that they also included other farmed areas, the 42,082 acres of improved land shown for them in table 8 is not inharmonious with the 34,370 acres of irrigated land in the Valley between White Rock Canyon and San Marcial reported by Follett (see table 6), but falls far short of the 124,800 acres "under development" shown in Hedke's tabulation (table 7).

The Federal irrigation census of 1890 reported, for 1889, only 15,554 acres of irrigated land in the counties of Bernalillo, Socorro, and Valencia. The total farm area in the three counties was 173,465 acres, of which approximately 37,600 acres was "improved." In 1899 the same counties reported 28,511 acres irrigated and 48,438 acres improved. The corresponding census figures for 1909 (including Sandoval County) were 105,943 acres improved, 77,682 acres irrigated. The 1919 figures were 114,990 acres improved and 68,101 acres irrigated.

For the counties above what is now Sandoval (that is, Rio Arriba, Santa Fe, and Taos) the "improved" and "irrigated" acreage figures reported by the census were respectively as follows: (The "irrigated" figures are for the preceding crop years.) 1890, improved (approximately), 30,353 acres and irrigated, 14,146 acres; 1900, improved, 45,601 acres and irrigated, 35,914 acres; 1910, improved, 79,329 acres and irrigated, 103,339 acres; 1920, improved, 114,561 acres and irrigated, 116,225 acres. (Pl. 1.)

Census figures from the 1925 and later canvasses, for both the counties involving the area discussed in preceding paragraphs and the counties involving the Valley lands between White Rock Canyon and the Colorado State line are shown in table 9.

TABLE 9.—*Selected statistics of agriculture in Rio Grande Valley, N. Mex., from reports of the United States Census*

[illegible]

[illegible]	[illegible]		
	[illegible]	1930	[illegible]
State line to White Rock Canyon: [1]			
[illegible]	[illegible]	101,489	[3] 39,021
[illegible]	[illegible]	64,310	54,067
[illegible]	[illegible]	5,176	43,632
[illegible]	33,258	16,039	12,987
[illegible]	[illegible]	74,459	63,021
White Rock Canyon to San Marcial: [4]			
[illegible]	(2)	[illegible]	[illegible]
[illegible]	65,486	57,576	43,295
[illegible]	14,396	7,100	57,486
Crop land idle or fallow	[illegible]	14,527	14,402
[illegible]	87,390	58,919	91,498

[1] [illegible]
[2] Not reported.
[3] "Irrigated land from which crops were harvested" (in 1934). Hence does not include irrigated pastures, irrigated crop failure and irrigated fallow lands.
[4] Bernalillo, Sandoval, Socorro, and Valencia Counties.

While it is possible to make almost any showing desired from the statistics in the preceding paragraphs and tables, they disclose an approximate agreement on a total area which presumably would be agriculturally productive under favorable conditions of water supply and drainage. Although the census figures fairly well support Follett's acreage estimates for 1880 and prior years, and do not justify the 1850 and 1880 estimates shown in table 7, they nevertheless are not absolutely inharmonious with those shown for 1896 and the later years. Thus if, in the 1925 summations, the crop land harvested, crop-failure land, and idle or fallow land are taken to represent the then crop areas, the total (91,500 acres) does not have to be increased unreasonably from the "plowable" pasture to come to an approximation with Hedke's combined acreage of 124,800 acres in "acres under development" and "acres failed", and the latest figures provided by the census (1934) would likewise indicate a total developed area (115,000 acres) approaching the Hedke figure.

In brief, these comparisons, including Follett's descriptions, while not proving beyond question that anything like as much as 124,800 acres was ever irrigated

in a single year in the area between White Rock Canyon and San Marcial, do appear to support the supposition that lands making up such a total have used water productively from time to time in periods recent enough for present consideration.

A similar somewhat loose conclusion may be drawn from comparing the 1934 census total of harvested, failed, and fallow acreages in the Valley section above White Rock Canyon (110,686 acres) with Follett's 1896 total of 118,330 acres. Apparently the two Valley areas are of about equal weight as far as extent of agricultural development and possibilities are concerned.

In all the compilations, whatever the other indications, the handicap of short water supply stands out sharply. This, therefore, is no new circumstance, but the census figures for the 1934 crop year emphasize it strongly, since the areas of crop failure reported in both sections of the Valley were substantially larger than acreages of "irrigated land from which crops were harvested." Neither census nor other statistics are available to disclose how the crops above Cochiti fared in 1935, but the Middle Rio Grande Conservancy District made its first complete crop census in 1936, results of which were handed the Bureau of Agricultural Engineering in advance of the completion of the Bureau's 1936 tabulations of the vegetative cover. The latter showed 59,159 acres irrigated. (See table 123 and supplementary table B.) The acreages reported by the district are listed below:

	Acres
Alfalfa	17, 125
Small grains	16, 477
Corn	13, 596
Orchards and vineyards	1, 564
Gardens	3, 990
Vega (meadow) land	3, 500
Miscellaneous	5, 042
Total	61, 294

Pertinent crop statistics from the three most recent Federal census reports are shown in table 10. The 1929 figures represent irrigated crops; the others, all crops.

TABLE 10.—*Selected crop statistics for counties in Rio Grande Valley between Colorado State line and San Marcial, from reports of the United States Census*

Crop	Acres					
	State line to White Rock Canyon[1]			White Rock Canyon to San Marcial[2]		
	[illegible]	[illegible]	1934	[illegible]	[illegible]	[illegible]
Hay crops	27, 339	20, 433	[illegible]	25, 213	12, 657	17, 511
[illegible]	11, 070	4, 309	[illegible]	11, 563	837	2, 695
[illegible]	20, 957	13, 424	23, 309	25, 016	17, 489	17, 845
[illegible]	884	1, 684	2, 251	693	1, 521	2, 251
Orchard fruits, nuts, and vineyards	[illegible]	1, 542	1, 357	1, 897	1, 437	1, 875
Other crops	19	63	[illegible]	14	47	831

[1] Rio Arriba, Santa Fe, and Taos Counties.
[2] Bernalillo, Sandoval, Socorro, and Valencia Counties.

Middle Rio Grande Conservancy District is closely coextensive with the entire Valley area between White Rock Canyon and San Marcial, its upper terminus being Cochiti and its lower terminus about 3 miles below San Antonio. (Plates 13–16, incl.)

C. H. Howell, former chief engineer of the district, in an article published by the University of New Mexico (83) in 1935 says that the organization and construction of the district were attributable to conditions existing in the Middle Valley prior to 1930, when construction of the system was started, as follows:

1. A water-logged or seeped condition of about 85,000 acres of lands which were formerly cultivated.
2. The dangers of flood damage from the Rio Grande and its tributaries.
2. An obsolete and inefficient irrigation system.

The following paragraphs represent a condensation and rearrangement (by the Bureau of Agricultural Engineering) of Mr. Howell's description of these conditions and the means adopted for their correction:

For the portion of the river below Corrales the river bed is in most cases only a few feet lower than lands on either side. In the Socorro Division it is actually higher than the farm lands west of it. In times of high water the tendency is for the flood waters to seek out the low places and form entirely new channels through the farm lands and villages. All Albuquerque, not on the mesa, is built in the flood water channel of the Rio Grande.

To remedy this condition a system of intercepting drains was laid out near and parallel to the river channel. These drains are some 10 feet deep at their upper ends and are built on a grade flatter than that of the river itself. They end in practically no cut and the water surface in the drain meets the low-water surface elevation of the river.

These riverside drains overlap; above the lower end of one drain another is started, so as to drain the area which would not be affected by the first drain because that drain is there no lower than the river. To drain the interior low-lying areas, interior drains were dug. These are located, in general, through the lowest lands and discharge into the riverside drains.

The material excavated from the riverside drains was used to form levees. Thus one handling of the material produced both a levee and a drain. The levees are from 8 to 10 feet high, so spaced as to pass 40,000 second-feet of water at the upper end of the district and 50,000 at the lower end. Those immediately adjacent to Albuquerque have been raised and are designed to handle about 75,000 second-feet. Considerable straightening of the river by cut-offs has also been done. Levees built total 181 miles, and about 40 miles of pile and wire protection have been installed.

At the beginning of the investigation of this project the land was served by 60 irrigation ditches, all primitive, generally small, and without permanent diversion dams or adequate headworks. Their structures were inadequate for economical distribution and use of water. However, before the Rio Grande became in reality an exaggerated arroyo, the old primitive ditches were made to serve. As the river channel filled, the difficulties of operating the ditches increased rapidly. For instance, in many cases, it was necessary each year to construct long diversion dams of sand, to corral the low flows which formerly had come directly into the heading but then wandered through the sands

[illegible] selves, numerous canals ran parallel to each other for miles. Each mile required its separate maintenance and cleaning. The owners of each ditch sought to get all the water in time of shortage and keep others from getting theirs.

A new irrigation system has been built, but the old system has not been entirely abandoned. For convenience, the district has been divided into four construction and operating divisions: [illegible] diversion dam, main canal or canals, new lateral system, and old ditches, which have been revamped.

El Vado dam and reservoir is considered a fifth division. The dam is built across Chama River in Rio Arriba County, about 17 miles west of Tierra Amarilla. It is a gravel embankment, 1,300 feet long and 180 feet high, with upstream slope of 1½ to [illegible] with vertical concrete cut-off wall, which is carried down to solid rock. The downstream slope is 2 to 1 and is formed of boulders and loose rock. The spillway is an open steel-lined chute, placed in a shale and sandstone cut which is 80 feet deep. The spillway is controlled by an automatic radial gate 23½ feet high and 36 feet wide. The outlet works consist of a 78-inch steel penstock placed in the 12-foot diameter diversion tunnel, and controlled at its upper end by a butterfly valve and at its lower end by two 48-inch balanced valves.

The spillway has a discharge capacity of 20,000 second-feet before the dam is overtopped. The outlet works have a maximum capacity of 1,500 second-feet. An auxiliary spillway or blow-off plug is formed by means of a low dyke which closes a saddle in the right rim of the reservoir. The top of this dyke is 1.5 feet below the top of the dam, so that before the dam can be overtopped, 1.5 feet of water will pour over the dyke and wash it out. It is estimated that when this spillway blows, 50,000 second-feet will be discharged. The storage capacity of the reservoir is 200,000 acre-feet. (Pl. 1.)

No such elaborate corrective construction has been undertaken in the Valley sections above Cochiti. There the 1930 irrigation census listed 11 irrigation storage reservoirs with a total capacity of approximately 40,000 acre-feet (not including the El Vado storage, of course). No irrigation wells, either flowing or pumped, were reported. The 1930 drainage census reported no organized drainage enterprise in the three upper counties.

Pueblo Irrigation

Not to be overlooked in any presentation of the past and present status of irrigation in Rio Grande Valley is the story of the Indian pueblos. Such a description was contributed by Gen. H. F. Robinson, then supervising engineer of the United States Indian Service, to Hosea's 1928 report (32), and quoted by various other writers. It is again reproduced in the following paragraphs and table 11, being considered generally pertinent to the present circumstances notwithstanding various developments (such as the creation of Middle Rio Grande Conservancy District) since its preparation:

The water rights for the Pueblo Indians of New Mexico are the oldest on the Rio Grande and its tributaries, and the United States claims priorities for such rights over any other claims whatsoever.

When the Spanish Conquistadores first arrived in this country, they found the Pueblo Indians diverting water from the streams and cultivating the irrigated lands. Today the Indians are doing this, very much as their forefathers did it, using the same general methods, diverting the water in the same ditches and irrigating the same lands as in 1540. The Government, through the Indian Service, has assisted the Indian in improving his ditches and providing structures for the diversion and control of the water.

From time to time, beginning almost as soon as the crown of Spain gave specific grants to the various Indian communities in the year 1692, non-Indians have gained a foothold on the grants and have acquired certain rights of occupancy and possession both of land and of water with which to irrigate the lands. * * *

Inasmuch as until the title to the lands and water are extinguished as to the Indians, they may still be considered as Indian, and a statement as to the area of land occupied by the non-Indians have been included herewith.

There is presented in tabular form a list of all of the pueblos showing (a) the source of water, (b) the number and (c) the length of their canals and (d) and (e) the acres of land under canal on these grants for which water is claimed. The list does not include figures for the non-Indian lands on the Santa Clara Grant.

TABLE 11.—*[illegible] Rio Grande Valley, N. Mex. (after Robinson)*

[In acres]

Pueblo	[illegible]	Canals		Irrigable area [illegible]	
		Number	Total [illegible]	Indians	Non-Indians
[illegible]	[illegible]	[illegible]	17	[illegible]	None
[illegible]	[illegible]	[illegible]	10	1,806	695
[illegible]	[illegible]	[illegible]	[illegible]	6,352	[illegible]
[illegible]	[illegible]	[illegible]	13.5	1,600	311
Laguna	[illegible]	[illegible]	33	3,020	[illegible]
Nambe	[illegible]	[illegible]	9.5	1,490	1,093
Picuris	[illegible]	3	2.7	[illegible]	2,930
[illegible]	[illegible]	1	[illegible]	3,145	[illegible]
[illegible]	[illegible]	[illegible]	18	4,116	17
[illegible]	[illegible]		[illegible]	[illegible]	1,118
San Juan	[illegible]	3	12.1	887	690
	[illegible]	2		150	[illegible]
Santa Clara	[illegible]		[illegible]	[illegible]	[illegible]
	[illegible]	1	2	....	[illegible]
[illegible]	[illegible]	2	17	4,545	[illegible]
[illegible]	[illegible]	1	[illegible]	[illegible]	170
[illegible]	Rio Lucero and Rio Pueblo...	[illegible]	26.6	[illegible]	2,956
Tesuque	Rio Tesuque..................	[illegible]	5.3	811	[illegible]
[illegible]	Rio Jemez....................	[illegible]	[illegible]	1,229	None
Total				[1]37,808	12,246
[illegible] only.				22,727	3,245

[1] [illegible] Guachupangue (from Santa Clara Creek) and Espanola and north has been lost to the Indians.

[illegible]

The agricultural use of these pueblo lands is illustrated by tables 12 and 13, which comprise data supplied by the Bureau of Indian Affairs. Table 12 represents the year 1930 and five pueblos only, these being the only data along the lines shown which are available for the group. Table 13 is more comprehensive in providing a record of cropped acreages over a long period for all but one of the 18 pueblos listed.

TABLE 12.—[illegible] *Pueblo* [illegible] *Middle Rio Grande Conservancy district, 1930*[1]

[In acres]

Pueblo	Irrigable area						Unirrigable area		
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Cochiti	[illegible]	[illegible]	822	226	394	0	332	[illegible]	2,464
Santo Domingo	[illegible]	[illegible]	1,697	401	1,124	151	205	980	[illegible]
San Felipe	1,168	[illegible]	1,506	[illegible]	[illegible]	26	225	1,180	[illegible]
Santa Ana	[illegible]	0	[illegible]	[illegible]	278	23	275	460	1,842
Sandia	[illegible]	42	740	1,107	1,425	104	171	[illegible]	3,897
Isleta	[illegible]	[illegible]	3,467	1,397	828	41	305	1,410	[illegible]

[1] District rights-of-way are not included.
[2] [illegible]

A reasonable representation of the agriculture practiced is provided by the 1936 records of Taos, Acoma, Cochiti, Laguna, and Picuris pueblos. These, consolidated, show a total cropped area of 4,290 acres, distributed as follows: Alfalfa, 1,007 acres; beans, 39 acres; chili, 7 acres; corn, 1,977 acres; other cereals, 1,017 acres; native grasses, 13 acres; orchards and vineyards, 97 acres; gardens, 133 acres. Thus corn and other cereals constituted 70 percent of the cropped area, and alfalfa 23 percent of the remainder.

Lower Valley

Although without as long an agricultural history, the valley areas below San Marcial have had farming characteristics similar to those of the Middle Valley. The modernization process now going on between Cochiti and San Marcial at the hands of the Middle Rio Grande Conservancy District is not unlike that undertaken only 20 years ago in Mesilla and El Paso valleys through the medium of the United States Bureau of Reclamation.

Follett's investigation preceded the creation of the Bureau's Rio Grande project by a considerable period but paved the way for it in ways the recital of which is not essential to this discussion. His acreage tabulation continued below San Marcial and ended at the pass above El Paso, so including the area now submerged by the storage behind the Elephant Butte Dam, the two small valleys (Palomas and Rincon) between that structure and Selden Canyon, and Mesilla Valley complete. He discussed the agriculture of El Paso Valley but presented no statistical history of it. At the time of his survey, what is now Hudspeth County was a part of El Paso County. The present Hudspeth Conservation and Reclamation District of course did not then exist, its creation (1924) postdating that of Rio Grande project by several years.

Follett's descriptions of the areas between San Marcial and El Paso were as follows:

District No. 16, Rincon.—District No. 16 extends from San Marcial to old Fort Selden, at the upper end of the Mesilla Valley, and I have named it the Rincon district. Just below San Marcial the river swings to the westward, running around Fra Cristobal and Caballo Mountains, which form the western battlements of the Jornado del Muerto. The bluffs are near together and leave between them only small valleys until the river turns eastward again around the Caballos, toward Rincon. There the valley widens and four-fifths of the tillage in the district is found in an almost solid body, which is watered by two large ditches, the Colorado and Loma Padre.

This country was overrun by the Apaches until about 1860, and no settlements were made until 1862 or 1863. Then part of the small upper valleys were occupied, and a few years later the lower and larger valleys was settled and the Colorado ditch built. About 1884 some people took up the remaining small valleys. In 1892 a large number of families who had become disheartened by the continued failures of crops in the El Paso and the lower end of the Mesilla valleys left that country and, moving into the bosque above Rincon, took out the Loma Padre ditch, irrigating their first crop in 1893. The colony is now

TABLE 13.—*Cropped areas in Indian pueblos along Rio Grande and tributaries, New Mexico, by years, 1917 to 1936 (except 1919, 1920, and 1935)*

[In acres]

Year	Taos	Acoma	Cochiti	Isleta	Jemez	Laguna	Nambe	Picuris	Pojoaque[1]	Sandia	San Felipe	San Ildefonso	San Juan	Santa Ana	Santa Clara	Santo Domingo	Tesuque	Zia
[illegible]	2,470	[illegible]	312	3,600	[illegible]	[illegible]	200	[illegible]		[illegible]	[illegible]	175	486	[illegible]	412	900	320	232
[illegible]	3,265	(1)	402	2,099	[illegible]	(1)	(1)	[illegible]		[illegible]	[illegible]	(1)	412	95	505	[illegible]		246
[illegible]	1,888		329	(1)	1,446	(1)	232	[illegible]		[illegible]	[illegible]	[illegible]	596	[illegible]	[illegible]	[illegible]	282	445
[illegible]		[illegible]	341		1,473	[illegible]	224	[illegible]		862	819	173	462	600	301	[illegible]	262	343
[illegible]	1,522	413	287	[illegible]	1,500	[illegible]	117	[illegible]		927	836	214	723	653	392	857	142	392
[illegible]		551	293	2,500	1,528	[illegible]	[illegible]	[illegible]		927	915	[illegible]	847	377	472	463	308	389
[illegible]	1,248	393	334	2,525	1,559	[illegible]	[illegible]	[illegible]		[illegible]	815	217	687	812	469	[illegible]	[illegible]	389
1926	1,173	863	329	2,400	1,405		81	[illegible]		[illegible]	1,168	81	500	1,003	215	755	61	286
1927	1,586	503	(1)	[illegible]	1,407	1,448	116	[illegible]		[illegible]	[illegible]	100	418	1,010	148	(1)	101	[illegible]
[illegible]	1,623	485	360	2,400	1,407	1,385	115	[illegible]		713	1,168	[illegible]	473	674	232	1,411	[illegible]	292
[illegible]	1,208	(1)	455	1,880	1,435	(1)	140	[illegible]		763	1,168	[illegible]	653	1,003		1,050	118	315
[illegible]	1,211	582	[illegible]	2,642	1,439	1,355	117	[illegible]		763	1,168	162	586	1,003	336	[illegible]	131	350
[illegible]	1,394	[illegible]	679	2,705	1,045	1,522	74	[illegible]		611	1,118	148	578	406	222	1,506	[illegible]	190
1932	1,959	749	[illegible]	3,040	1,134	1,659	[illegible]	112		671	1,012	222	703	587	287	1,397	[illegible]	164
[illegible]	2,368	958	629	2,946	1,131	1,687	253	174		672	1,078	203	671	608	343	1,366	227	373
1934	1,505	956	[illegible]	2,435	1,001	1,503	191	134		622	1,030	131	628	582	[illegible]	1,179	217	[illegible]
[illegible]	1,269	868	628	(1)	[illegible]	1,336	[illegible]	188		[illegible]	(1)	(1)				[illegible]	190	(1)

[1] [illegible]

[illegible] about 3,600 acres, all of which has been reclaimed from the bosque in the last 4 years.

The water supply of district No. 16 is rather precarious, but the irrigators are skillful and crops are raised with a small amount [illegible]

District No. 17, Mesilla Valley.—The Mesilla Valley extends from old Fort Selden to the pass, some 5 miles above El Paso. Together with the El Paso Valley below the pass, it forms the most fertile area along the whole river. The altitude of the Mesilla Valley is a little under 4,000 feet. The climate is warm, and fruit of remarkably fine flavor is raised in abundance.

I could not learn, however, that the valley was settled at an early day. Dona Ana was in existence in 1846, but was then new. It is probable that the Apaches prevented earlier Spanish or Mexican occupation.

The valley filled up rapidly after 1846. In 1865 some 35,000 acres were in cultivation. In that year the river made a change of channel, breaking up the ditches, and the acreage decreased somewhat. The year of 1879 was one of poor water supply. As a result of this, the Picacho ditch, watering some 2,500 acres west of the river, about opposite to Las Cruces, was abandoned. A considerable area under the Dona Ana ditch was also soon after abandoned, the land watered by it decreasing from 7,000 acres in 1882 to 4,600 acres in 1888. All of this 2,400 acres still remains idle except some 800 acres, which a man named Schiller has colonized and is irrigating with water pumped from wells. This area is not included in my estimate of acreage.

In 1884 a severe flood started another change of channel near the lower end of the valley, and the high waters of 1885 and 1886 completed the work. This change of channel cut into several pieces La Union ditch, previously watering some 4,000 acres, and caused the temporary abandonment of nearly all of the land. In 1892 the people took out a new ditch on the east side of the river, the old one having been on the west side, and are now reclaiming and cultivating their old land.

The changes of acreage since 1880 have been so many in the Mesilla Valley that I append to the list of ditches for the district [illegible] 1880 by the individual ditches.

Table 14 shows Follett's estimates of acreages irrigated between San Marcial and El Paso for the years ending with 1896.

Follett's description of El Paso Valley (the Texas part of which roughly corresponds to the portion of the Rio Grande project below El Paso) was as follows:

This valley was occupied by the Spaniards over 300 years ago. In 1600 Paso del Norte (now called Juarez) was an important town, and records are in existence over 280 years old which refer to the Acequia Madre of Paso del Norte as being then in use.

Owing to the limited time at our disposal, and also to the fact that the use of water which had supposedly injured this valley was all, of course, above it, we did not extend our detailed examination below El Paso. From all I could learn, however, from old inhabitants, I should judge that in former years some 40,000 acres of land were tilled in this valley, more than half of which was on the Mexican side of the river. * * *

* * * I am unable to give you an estimate as to the acreage now cultivated in this valley, but can safely say that it is considerably less than the amount formerly tilled. * * *

[illegible] early Federal census statistics for Dona Ana County, which now includes the greater part of the area in New Mexico below Elephant Butte Dam. Ignoring changes of boundaries, they were, for improved land in farms: 1860, 14,490 acres; 1870, 17,184 acres; 1880, 25,786 acres (24,246 acres "tilled, including fallow and grass in rotation, whether pasture or meadow", and 1,540 acres "permanent meadows, permanent pastures, orchards, and vineyards"). In 1890 approximately 15,550 acres was reported as "improved" in Dona Ana and Sierra Counties. The two counties reported 29,906 acres improved and 19,890 acres irrigated (in 1899). Corresponding figures for 1910 were 37,415 acres and 35,869 acres, respectively; for 1920 the acreages were 49,876 and 60,756. The census total for irrigated land in the two counties in 1929 was 81,726 acres; in 1934 the census reported 67,543 acres in "irrigated land from which crops were harvested."

TABLE 14.—*Areas irrigated in Rio Grande drainage basin from San Marcial, N. Mex. to El Paso, Tex., as reported by Follett* [illegible]

Year:	*Area*
Prior to 1880	37, 350
1880	34, 850
1881	34, 850
1882	34, 850
1883	34, 450
1884	[illegible]
1885	27, 690
1886	27, 290
1887	27, 340
1888	27, 440
1889	27, 590
1890	28, 140
1891	28, 190
1892	28, 990
1893	30, 390
1894	[illegible]
1895	35, 600
1896	36, 800

The early census figures for El Paso County farms were as follows: 1860, improved land, 4,456 acres; unimproved, 7,150 acres. In the 1870 census report, only 50 acres of improved land is shown. In 1880 the "improved" total was 14,024 acres, comprised of 10,587 acres "tilled, including fallow and grass in rotation whether pasture or meadow", and 3,437 acres "permanent meadows, permanent pastures, orchards, and vineyards." Texas was not included in the 1890 and 1900 irrigation censuses, but in 1910 El Paso County reported 16,772 acres of improved land in farms and 23,308 acres irrigated (in 1909). The corresponding 1920 figures were 30,119 acres and 20,259 acres. The irrigated acreage for 1929 was 65,442 acres, and in that census Hudspeth County reported 14,010 acres irrigated. "Irrigated land from which crops were harvested" in 1934 was 51,518 acres for El Paso County, and 12,093 acres for Hudspeth County.

Bureau of Reclamation estimates for areas irrigated in Hudspeth County for the years 1920 to 1926 are as

TABLE 15.—Irrigated areas in Rio Grande project, New Mexico and Texas, as reported by United States Bureau of Reclamation, 1922 to 1936

[illegible]

Year	New Mexico: Alfalfa	New Mexico: Cotton	New Mexico: Miscellaneous	New Mexico: Not cropped	New Mexico: Total	Texas: Alfalfa	Texas: Cotton	Texas: Miscellaneous	Texas: Not cropped	Texas: Total	Entire project: Alfalfa	Entire project: Cotton	Entire project: [illegible]	Entire project: [illegible]	Entire project: Total
1922	[illegible]	[illegible]	[illegible]	[illegible]	48,996	[illegible]	7,276	11,119	2,063	35,221	33,312	9,909	35,822	5,177	[illegible]
1923	[illegible]	12,981	16,652	1,014	52,415	12,932	17,115	[illegible]	1,363	39,956	31,700	[illegible]	[illegible]	5,377	92,371
1924	[illegible]	[illegible]	12,912	5,390	[illegible]	[illegible]	32,122	6,000	[illegible]	[illegible]	25,152	58,721	[illegible]	12,876	115,991
1925	13,141	[illegible]	12,066	3,291	67,458	10,018	42,113	5,201	5,821	63,453	23,159	81,373	[illegible]	9,112	130,911
1926	14,652	[illegible]	13,953	[illegible]	77,464	11,181	41,473	5,735	6,670	65,059	[illegible]	83,337	19,688	13,665	142,523
1927	15,140	[illegible]	16,534	2,139	74,042	13,550	[illegible]	9,592	1,683	63,511	28,690	78,915	26,126	3,822	137,553
1928	10,929	[illegible]	10,334	1,351	77,662	9,622	49,121	4,544	2,375	65,662	[illegible]	104,169	14,878	3,726	[illegible]
1929	11,236	[illegible]	9,754	843	78,775	9,109	48,483	4,250	3,580	65,422	20,345	105,425	14,004	4,423	144,197
1930	13,730	[illegible]	13,267	842	[illegible]	11,904	44,255	5,941	4,058	66,158	25,634	94,865	19,208	4,900	144,607
1931	16,017	43,922	17,696	1,579	79,214	12,753	39,416	7,573	5,333	[illegible]	28,770	83,338	25,270	6,912	144,290
1932	[illegible]	[illegible]	[illegible]	1,684	[illegible]	14,792	[illegible]	11,175	1,234	58,147	[illegible]	71,056	32,695	2,918	137,449
1933	[illegible]	40,140	23,895	[illegible]	79,557	12,712	32,514	13,288	1,135	59,649	26,672	72,654	37,183	2,697	[1] 139,206
1934	14,269	33,880	20,643	3,593	72,385	13,007	30,038	[illegible]	1,677	[illegible]	27,276	63,918	32,628	5,270	[2] 129,092
1935	12,326	32,004	17,087	4,008	65,425	13,910	[illegible]	10,691	1,409	[illegible]	26,236	60,644	[illegible]	5,417	[illegible]
1936	15,478	44,513	14,290	[illegible]	[illegible]	11,822	[illegible]	[illegible]	2,991	60,358	30,300	[illegible]	[illegible]	[illegible]	[illegible]

[1] Cropped area excludes [illegible]
[2] [illegible]
[illegible] acres of cotton [illegible]

follows: 1,011 acres in 1920, 1,420 acres in 1921, 6,153 acres in 1922, 6,126 acres in 1923, 8,964 acres in 1924, 10,800 acres in 1925, and 12,540 acres in 1926.

Irrigated area statistics for the Rio Grande project have been assembled yearly since 1922 by the Bureau of Reclamation, and figures pertinent to this discussion, as supplied by Project Superintendent Fiock, appear in table 15.

Especially notable in table 15 is the statistical history of cotton and alfalfa, the heavy preponderance of those crops in the project's agriculture, and the agreement of their acreage figures with the corresponding Federal census figures. The alfalfa acreage has been fairly constant, but the cotton acreage, while in 1935 substantially lower than its 1930 peak, has assumed an advanced lead over all other crops since as recent a year as 1922. In fact, only 5 years before that date cotton was unimportant in its proportion of the project's cropped acreage. While showing by no means the stable position held by alfalfa—its fluctuations being, in fact, emphatic—cotton, nevertheless, has been the project's characteristic crop for the past dozen years, and while the alfalfa acreage supports a local hay and dairy industry, much of it now has its principal importance in the crop rotation program built around cotton, and its migrations have accorded, in some degree, with those of cotton.

The close agreement between Bureau of Reclamation acreage statistics for Rio Grande project and census figures for Sierra, Dona Ana, and El Paso Counties appears in the following comparison. The figures are acres.

[illegible]	[illegible]	[illegible]	[illegible]
Cotton			
Bureau of Reclamation	58,721	105,425	[illegible]
Bureau of the Census	62,019	107,532	[illegible]
Alfalfa			
Bureau of Reclamation	25,152	20,345	27,276
Bureau of the Census	25,634	22,541	25,631

As in the case of the Rio Grande project, the preponderant crop in Hudspeth County is cotton. Thus three-fourths of the 1934 acreage in "irrigated land from which crops were harvested" (12,093 acres) was in cotton; 10 percent was alfalfa, and most of the remainder was in other hay and forage crops. In 1929 almost the whole irrigated acreage was in cotton.

Irrigation Works

The irrigation plan of the Rio Grande project involves the storage of flood waters of the Rio Grande in a reservoir controlled by Elephant Butte Dam, about 12 miles west of Engle, N. Mex., and the diversion of water from the river about 24 miles below for watering lands in Rincon Valley; about 60 miles below for the irrigation of the upper Mesilla Valley under the Leasburg diversion dam; about 80 miles below for the irrigation of the lower Mesilla Valley under the Mesilla Dam; and about 120 miles below for supplying water to lands in El Paso Valley and furnishing 60,000 acre-feet per annum for use on land in El Paso Valley on the Mexican side of the river. The United States claims all waste, seepage, spring, and percolating water arising within the project. All irrigation works required for Palomas and Rincon valleys were new; those for the Mesilla Valley include a diversion dam and several miles of old canals, as well as a diversion dam 5½ miles southwest of Las Cruces and many miles of reconstructed canals leading from it. The distributaries in El Paso Valley likewise supplemented and improved previously existing canals. (Plates 1, 18–21, incl.)

Under construction is a new storage unit below Elephant Butte Dam, which will submerge the area now farmed between the dam site at Caballo and Elephant Butte Dam. Caballo Dam has several purposes in addition to that of storage of previously uncontrolled flood waters, among them being regulation of present storage to the possible future extent of permitting the use of that storage for power development. (Pl. 18.)

Also about to be constructed is a new diversion dam above the present international boundary dam, and the necessary appurtenant canals, by which the 60,000 acre-foot delivery to Mexico will be made more accurately than is possible with the structure now used. (Pl. 20.)

An extensive system of drains was constructed between 1916 and 1920, to serve practically the entire area. Drainage and waste waters leaving the project are delivered to the Hudspeth County district, constituting the principal agricultural supply for that enterprise notwithstanding their high salinity. (Plates 19–22, incl.)

An elaborate channel-straightening program between El Paso and Fort Quitman, in progress for several years under the direction of the International Boundary Commission, is expected to be extended to the Mesilla Valley section. In the section below El Paso this will involve some shifting of jurisdiction between the two nations, and has already had the effect, although in a relatively unimportant degree, of removing or withholding certain lands from productive use in order to facilitate the Commission's operations. This status is temporary, the expectation being that such of these areas as are of agricultural value will be put to use as soon as the progress of the Commission's program permits. (Plates 21–22.)

PART III

SECTION 2.—SOME CONDITIONS AFFECTING USE OF WATER

Several factors influence the use of water in irrigation besides evaporation and the moisture requirements of plants which have separate attention elsewhere in this report. Difficulties of distribution, vagaries of climate, soil characteristics, and differing methods of applying water are among them. In the following paragraphs these conditions are described in such detail as seems necessary to provide a general understanding of irrigation needs.

San Luis Valley

Large-scale farming is a striking feature of the agriculture in San Luis Valley. In 1930 the average size of the irrigated farms[1] in the seven counties which include the Colorado portion of the Valley was almost 400 acres (398 acres), and more than half this average area was irrigated. The list below shows how the irrigated farms of the Valley counties were grouped in the 1930 census reports:

	[illegible] farms
Under 3 acres	19
3 to 9 acres	197
10 to 19 acres	181
20 to 49 acres	435
50 to 99 acres	427
100 to 174 acres	948
175 to 259 acres	296
260 to 499 acres	556
500 to 999 acres	204
1,000 to 4,999 acres	131
5,000 to 9,999 acres	11
10,000 acres and over	5

Thus the predominant size (100 to 174 acres) is less than the average size (398 acres), and there are more farms of less than 100 acres each than there are in the predominant size group; conversely, however, there are almost as many larger than the predominant size, and the group next in number to that size group is the one inclusive of farms ranging from 260 to 499 acres each.

Such large farms require capacious distributaries and liberal heads of water. Farming operations are typified by the extensive use of machinery, although horses are also widely used.

[1] [illegible]

Climate

San Luis Valley's climate is marked by almost continuous sunshine, small rainfall, extremes of temperature, and a high wind movement. Precipitation varies widely from season to season and at different places. On the basis of long-time averages farmers can depend upon only about 7 inches of precipitation, but the records producing this average include figures more than twice its amount, as well as others of less than half. However, the heaviest rainfall of the year occurs in July and August, when it is most needed by crops. In the usual summer these rains are of little direct benefit to the crops, but the streams are flooded by run-off from adjacent hills and so sometimes provide water for irrigation for a few days. In exceptional years such as 1936, the summer precipitation in the Valley itself may be heavy enough at times to benefit the crops directly.

The least agreeable feature of the Valley's climate is the high winds occurring in the spring. Their general direction is northeastward, and they blow steadily for days at a time. In some of the lightest soils, newly planted crops may be damaged severely by winds of this nature

Table 16 shows that over a period of 37 years the average growing season at the Garnett station was only 95 days. July 7 was the latest date of killing frost in the spring and August 13 the earliest date of killing frost in the autumn. The average length of growing season, for the four stations shown in the table, was 108 days, with the average date of last killing frost in the spring, May 30, and average date of first killing frost in autumn, September 19

TABLE 16.—*Dates of killing frost and length of growing season as recorded at various United States Weather Bureau stations in San Luis Valley, Colo.*

[illegible]	[illegible]	[illegible] date of last killing frost in spring	[illegible] date of [illegible] ing frost [illegible]	[illegible] length of [illegible] season, [illegible]	[illegible] killing frost in [illegible]	[illegible] date of killing [illegible]
Del Norte	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Garnett	[illegible]	June 9	Sept. 12	[illegible]	July 7	Aug. 13
[illegible]	[illegible]	[illegible]	Sept. 13	[illegible]	June 20	[illegible]
Saguache	[illegible]	May 28	Sept. 25	[illegible]	June 26	Aug. 28

Table 17 shows, from all records available, that the maximum temperature is 102° (at Saguache Weather

[illegible] and the lowest temperature [illegible] at (Garnett station). The seasonal precipitation was 15.64 [illegible] in 1917 only [illegible] to set the minimum record.

[illegible] *recorded at various United States Weather Bureau stations in San Luis Valley, Colo.*

Station	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Del Norte	[illegible]	58.1	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	23.0		[illegible]	−41	45	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]		41.7	[illegible]	−33	[illegible]	11.57 (1914)	[illegible] (1917)	[illegible]
[illegible]		[illegible]		43.9	102	[illegible]	37	[illegible] (1923)	2.88 (1896)	[illegible]

Soils

The soils of part of the Valley have been described as follows by the United States Bureau of Chemistry and Soils (77):

> [illegible] lacustrine deposits. Since the subsidence of this lake the [illegible] issuing from the mountains onto the plain and by the action of the winds, while moisture and irrigation have done much to decompose the coarse sands, wherever standing water has accumulated or moisture has been continuously present in the soil.
>
> As a result of these changes, five types of soil are found in the area. The following table names these soils and gives the area of each:

[illegible]

Soil	Acres	Percent
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	34.2
[illegible]	[illegible]	8.9
[illegible]	[illegible]	5.7
[illegible]	[illegible]	2.2
[illegible]	101,920	

> [illegible] Even this soil is underlain at from 2 to 4 feet by gravel, and this [illegible] gravelly, sandy soils to distinguish them from soils which have a [illegible]

[illegible] It carries [illegible] by a coarse gravelly subsoil. It irrigates readily and drains well except on the lower lands.

[illegible] Valley sand represents a little more than one-third of the entire area. It is a light, porous, incoherent leachy soil consisting mainly of disintegrated volcanic rock. At depths ranging from 2 to about 4 feet it is underlain by a gravelly porous subsoil. It drains well, does not puddle nor become sticky when wet, and requires frequent irrigation to produce crops. The lower lands of this type are waterlogged.

The river bottom soils vary from a sandy loam to a heavy clay loam, and all are underlain at depths of a few feet by a coarse gravelly subsoil. The sandy loam occurs widely along the river bottom and is one of the best of the Valley soils. These soils are largely given over to hay meadows, the yearly flooding of which has kept them fairly free of alkali. All but the heaviest drain readily.

Agricultural Practice

In most of the water districts of the valley, little system is necessary in handling the water. The spring flood rises rapidly but it also recedes rapidly and the stream is soon dry at most headgates. When this stage is reached, the commissioner divides the available water among the few early priorities which can be satisfied, and watches the gates above to see that no water is diverted unlawfully.

On some of the streams the flood recedes more slowly and the headgates must be closed, but it is customary to shut even these streams off in blocks including priorities of from 1 to 5 years. There is often considerable daily fluctuation in the flow of the Rio Grande during the flood period.

Natural conditions are so good that the cost of maintaining ditches is relatively low. Most ditches are built on straight lines. There is almost no sidehill construction and very little fluming. Breaks are rare, water seldom being carried in the ditches above the level of the adjacent land. Ditches which must pass through marshes on low gradients are subject to loss of capacity through plant growth, and no satisfactory way has been found to cope with this condition.

When water is plentiful in the spring its distribution after it is in the canal does not present difficulties. When it becomes scarce some form of rotation is resorted to, either between laterals or between "divisions" of the ditch. On ditches where division boxes are used the supply is prorated officially until exhausted,

[illegible]

though the farmers frequently make exchanges among themselves to get usable heads.

The length of the irrigation season varies with the time water is available. Under ditches which may divert at all times irrigation usually begins about April 15 and continues until the middle of October, making a season of approximately 180 days. Fall irrigation is not widely practiced. Under ditches holding late rights the season is from May 1 to July 1, or an average of 60 days which may be lengthened a few days by later floods. However, along Saguache Creek where hay must be cut about July 1 to avoid foxtail, irrigation is begun as early as March 15 to thaw the soil and give the meadows a quick start, and where fall irrigation is practiced water is carried as late as November 1 in a number of ditches.

Methods of Irrigation.—Various methods are used in applying water to the land. Flooding is most widely used, with subirrigation the next most extensive method. However, subirrigation is confined largely to areas under ditches diverting from Rio Grande. The furrow method is also used widely but principally for potatoes, sugar beets, vegetables and crops on land too steep for flooding. Borders and checks are employed on a limited acreage.

Subirrigation consists in raising the ground-water level by seepage from small ditches placed at intervals over a field so that the surface soil will be moistened by capillarity.

The soil best adapted to this method is the porous sandy loam which is underlain by an impervious stratum. Heavy soils are not porous enough to be subirrigated successfully. Best results are obtained where the slope of the land is from 5 to 10 feet per mile. The method has been successful with most crops.

The seed bed is prepared in the usual manner and the crop planted. The field ditches are made immediately either with plow and V, or with a ditching plow, which is the more economical and makes an even, loose ditch through which water seeps readily. The proper location of the ditches can be determined only by trial. Most of the land in the Valley has a uniform gentle slope, and the custom is to run the ditches parallel to the section lines in the direction having the least slope. They are spaced at intervals varying from 50 to 250 feet according to the character of the soil, the depth of the normal water table, and the amount of irrigation in the neighborhood affecting the water table.

At the proper time, which is usually when the ditches are finished or when the water becomes available, irrigation is begun by filling the field ditches as full as possible without flooding at any point or wasting over the blind lower end. The flow turned into each ditch is then regulated to compensate the amount of seepage from it. This seepage water flows downward rapidly and fills the subsoil to the point where moisture is drawn to the surface. When the surface becomes moist the flow in the field ditches is cut down so that only enough water flows to maintain the moist condition of the surface soil. The time required to "raise the sub" varies from 10 days to 6 weeks. The cost of subirrigation is very low.

There are many modifications of the method. Where the soil is thin, or leveling is impracticable for any reason, the field ditches are carried along the ridges. In the river bottoms, sloughs or old channels are dammed and kept full of water during the season. Drains are also dammed during the irrigation season to raise the water level. In other cases small reservoirs have been built to catch excess water, which is then allowed to seep from them.

Under ideal conditions, this method of irrigation could hardly be improved upon, but actual practice has developed a number of faults. The greatest objection is that frequently the farmer on the lower lands is drowned out. Control of the moisture in the surface soil within narrow limits is impossible. Under this system irrigation becomes a community, rather than a private, affair. It concentrates alkali on the surface quicker than any other system of irrigation.

Its chief advantages are simplicity and cheapness. The ease with which large fields can be irrigated by one

[illegible]

FIGURE 70.—Grain field in San Luis Valley.

man is another advantage. Under ditches with doubtful water supplies crops are often carried through to maturity by the water in the subsoil when the ditches fail early.

Most of the land reclaimed by drainage was once subirrigated; much of it is now being flooded. Many farmers in the subirrigation districts are convinced that better crops are raised by that method than any other, but facts upon which a comparison can be based are few. A number of ranches in the Valley are either flooded or subirrigated and as a general thing subirrigation is preferred to flooding. However, the question of cost enters here and the chances are that cheapness and a minimum of trouble are the factors which determine the use of subirrigation.

The condition of much of the subirrigated land which is feeling the effects of the gradual rise of the water table and the collection of alkali on the surface, could probably be improved by a change to surface irrigation.

The popular way of irrigating the large areas of pasture and native hay is the "wild flooding" method common throughout the Rocky Mountain States. Water is taken to the high point in the field and turned loose, and to direct it small ditches are thrown up at various positions in the field. The general custom is to keep the water running as long as it is available; or if hay is to be made, it is turned off a week or 10 days before the time for cutting. This method is primitive and wasteful. It is fortunate much of the water used in this manner soon finds its way back to the streams.

The method of flooding from field ditches used in the Valley does not differ from the practice elsewhere. Small ditches are plowed in the fields at intervals of [illegible] feet and water is turned on the field from them by cutting the banks. In a few cases permanent ditches equipped with wooden check boxes and gates are maintained, but on most farms the field ditches are plowed out each year and then filled in before the harvest. Dirt dams and canvas dams are used to check the water up to the [illegible].

Where [illegible] and [illegible] are [illegible] alternated they [illegible] by the [illegible] furrow method. In localities around the edge of the Valley where the land slope is too high for effective flooding, furrow irrigation is used for all crops except hay. Furrows are plowed about 3½ feet apart and a small head is run in each for from 12 to 36 hours. The length of the furrows varies from 200 feet to ¼ mile. Sometimes in irrigating crops in rows only alternate furrows are used.

Other methods of irrigation are used only to a limited extent. A few examples of the border method and the square and contour check methods may be found, but most of the checks were built for washing alkali out of the soil.

Middle Valley

Marked differences appear in a comparison of New Mexico farms and farming with those of San Luis Valley.

Size of Farms

Such differences are emphatic in the matter of size of farms. Whereas large-scale farming is the common type in San Luis Valley, small farms are the rule in Middle Rio Grande Valley. The average size of the San Luis irrigated farm is 398 acres; the corresponding average for the entire group of Rio Grande Basin counties above San Marcial is 95 acres.

Size of farms	[illegible]	
	Rio Arriba, Taos, and [illegible]	Bernalillo, Sandoval, Socorro, and [illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	213
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	31
[illegible]	30	[illegible]
[illegible]	[illegible]	30
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	3,298

Even this comparison is misleading, however, as the New Mexico average is distorted in somewhat greater degree than is the case with the San Luis figure, by a relatively few ranches of great size, some of them in sections of the counties not strictly within the Valley area. The facts are brought out more effectively by the list above, which is based on the 1930 census reports.

From the foregoing list it appears that in the northern group of counties more than one-third (37 percent) of the farms are less than 10 acres in size; nearly three-fifths (58 percent) have less than 20 acres. Somewhat more than four-fifths are smaller than the 95-acre Valley average. The predominant size, in fact, is represented by the 3-to-9-acres group.

In the four lower counties, which include the Middle Rio Grande Conservancy District, the comparisons are similar. Nearly two-fifths (38 percent) of the total number of irrigated farms have less than 10 acres each. More than two-thirds (67 percent) have less than 20 acres. Probably more than nine-tenths are smaller than the 95-acre Valley average. As in the case of the upper counties, the predominating size is represented by the 3-to-9-acres group.

Climate

While the climate continues distinctly arid throughout the New Mexico portion of the Valley, and in the northern part of the State retains the general characteristics described for the San Luis region, the reducing altitudes introduce modifications, so that a new set of conditions mark the Middle Valley areas. There the growing season averages 190 days. Frequent rains occur in the hot summers, producing an average precipitation of 5 inches between April 1 and September 30. Humidity is low. Prevailing winds are from the west and southwest.

Table 18 shows the pertinent facts relating to temperature and precipitation at four stations in the Middle Valley.

TABLE 18.—*Mean annual temperatures and precipitation in the Middle Rio Grande Valley, N. Mex.*[1]

[illegible]	[illegible]	Temperature (degrees F.) [illegible]					[illegible]	Annual rainfall, in inches		
		[illegible]	[illegible]	Mean	Maximum	Minimum		Maximum	Minimum	[illegible]
[illegible]	[illegible]	69.3	41.8	55.5	104	−10	[illegible]	16.30	3.29	8.21
[illegible]	6	70.7	39.6	55.3	102	−13	13	11.49	5.64	[illegible]
[illegible]	[illegible]	[illegible]	37.4	[illegible]	106	−25	44	16.37	2.15	8.62
Socorro	[illegible]	73.8	40.8	57.3	[illegible]	−16	46	22.10	4.12	10.27

[1] [illegible]

In table 19, the length of growing season is shown for three stations in the Middle Valley area.

TABLE 19.—*Length of growing season, Middle Rio Grande Valley, N. Mex.*[1]

[illegible]	Length of record, years	[illegible] date of last killing frost in spring	Average date of first killing frost in fall	Average [illegible] days	[illegible] killing frost in [illegible]	[illegible] date of killing frost in fall
Albuquerque	[illegible]	Apr. 13	Oct. 26	[illegible]	May 1	Sept. 17
[illegible]	[illegible]	Apr. 18	Oct. 19	[illegible]	May 13	Sept. 22
[illegible]	[illegible]	...do...	Oct. 21	186	[illegible]	Sept. 27

[1] [illegible] Weather Bureau records.

Surveys have not been made by the Bureau of Chemistry and Soils in the Valley areas above Cochiti, but the following paragraphs, abstracted from a report by that bureau (79), describe the soils of "the Middle Rio Grande Valley area":

The soils of the area are classed in three distinct groups according to their topographic position—those representing the material of the uneroded mesas or upland desert plains, those occupying the mesa slopes along the valley margin, and those of the valley floor. * * *

The soils of the mesa slopes have been identified as members of the Anthony series. They occur along the eroded slopes of the high plains bordering the valley, and are usually separated from the higher uplands by bluffs or an eroded escarpment. * * *

The material forming this group of soils consists predominantly of reworked material of the upland formation which has been assorted to some extent and deposited by surface waters as alluvial and colluvial fan and foot-slope deposits over the slopes below. To this in some localities there has been added a small amount of wind-blown material, removed from the Rio Grande bed during periods of low water. * * * The soils of the Anthony series are grayish brown or light brown to reddish brown in color, a reddish tint usually being perceptible. The subsoils to a depth of 6 feet or more are generally similar in color and character to the surface material. * * *

The series is distinctly arid and supports only a stunted growth of scrubby mesquite and other characteristic desert vegetation. * * *

The soils forming the valley floor have with two exceptions been recognized under the Gila series. The material giving rise to the Gila soils consists mainly of sediments brought down from regions to the north by the Rio Grande and deposited over the valley during periods of high water. It is derived from a wide variety of rocks, including sandstones, limestones, and metamorphic altered and igneous rocks, which may or may not contain conspicuous amounts of quartz-bearing minerals. * * *

To this has been added small amounts of alluvial wash and of wind-blown material from the mesa slopes. * * *

Numerous old abandoned river channels occur throughout the valley. Sometimes clay deposits several feet deep occur over limited areas of these channels, but most frequently the coarser material forming the old river beds is covered with only a few inches of heavy soil. The alluvial soils of the valley are thus still in process of formation. * * *

Considerable sedimentary material is also deposited each year over the entire irrigated portion of the valley by irrigation water. During the long periods of irrigation these deposits have increased until in places they are several feet deep.

Table 20 names and shows the relative extent of each of the several soil types in the Middle Rio Grande area. The distribution shown is believed to be fairly suggestive of that applying to the entire Middle Valley as considered in this report, although many variations are to be found throughout the larger areas.

TABLE 20.—*Areas of different soils in the Middle Rio Grande area, New Mexico*

Soil	Acres	Percent
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	8.1
[illegible]	[illegible]	6.6
[illegible]	11,072	6.3
[illegible]	[illegible]	6.2
[illegible]	4,160	2.4
[illegible]	[illegible]	1.7
[illegible]	2,752	1.6
[illegible]	[illegible]	1.2
[illegible]	1,600	[illegible]
Total	175,360	

Agricultural Practice and Crop Adaptability

Throughout the successive Valley areas from the Colorado line to San Marcial, agriculture still centers, as it has for many years, upon the hay and cereal (including corn) crops. The 1929 Federal census returns showed these as comprising by far the greater part of the cropped areas in both the section ending approximately at White Rock Canyon, and the Middle Valley area from Cochiti to San Marcial; in both cases the position of each of these two leading groups of cropped acreages was not greatly different, the cereals holding a slight advantage in each.

The preponderance of these crops does not mean that others are not important. In point of acreage, the legumes—mostly beans—are distinctly prominent, although not as much now as 10 or 15 years ago. Vineyards and orchard fruits, such as apples, pears, peaches, European and native plums and sour cherries, are raised throughout the area, and while of limited and localized importance as commercial crops, have nevertheless a well-established place in the Valley's agriculture. Truck gardening is rapidly becoming a profitable industry, especially around Albuquerque.

Water for irrigation from ditches is available between March 1 and November 15, so that no winter irrigation is practiced. The irrigation methods used are the flooding, border, and check methods for alfalfa; flooding for rough "meadow" land, and border, check, furrow and [illegible] methods for the other crops. Approximately [illegible] acre-feet of water is used annually in the Middle Rio Grande Conservancy District.

Lower Valley

Farms in the counties which include the Rio Grande project and the irrigated lands below it average somewhat larger (151 acres) than those above it in New Mexico, but are somewhat smaller than the San Luis Valley farms. As in the case of both other Valley sections, however, the average size is misleading, as the size-group which includes that average comprises only about 9 percent of the total number of farms. The predominating size-group in each of the four counties (Sierra, Dona Ana, El Paso, and Hudspeth) is the one ranging from 20 to 49 acres, and the farms which are smaller than those inclusive of the average size comprise more than four-fifths (83 percent) of the total number.

The 1930 distribution of the irrigated farms in the Lower Valley is shown in detail below:

	Number of farms
Under 5 acres	90
5 to 9 acres	[illegible]
10 to 19 acres	711
20 to 49 acres	[illegible]
50 to 99 acres	508
100 to 174 acres	[illegible]
175 to 259 acres	[illegible]
260 to 499 acres	75
500 to 999 acres	42
1,000 to 4,999 acres	37
5,000 to 9,999 acres	[illegible]
10,000 acres and over	[illegible]

Climate

The climate of the Lower Valley is characteristically arid, with cool nights but high temperatures during the day. The mean relative humidity is low. There are very few cloudy days and but little rainfall. These factors contribute to a high evaporation rate.

The average annual rainfall is only 8 to 10 inches per year, about two-thirds of this coming during the growing season. Only a relatively small proportion of this rainfall becomes of value for crop production, however, since so much of it comes in numerous light showers that cannot penetrate far into the soil and is soon lost by evaporation.

Records taken over a period of 43 years to 1936 exclusive at State College give an average length of growing season of 200 days as shown in table 21, where frost data for three different locations along this section of the Rio Grande over a long period of years are summarized.

TABLE 21.—*Length of growing season, Lower Rio Grande Valley, New Mexico and Texas*

Place	[illegible]	[illegible] last killing frost [illegible]	[illegible] in fall	[illegible] season, [illegible]	[illegible] date of [illegible] frost in [illegible]	[illegible] killing frost in fall
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	200	May 13	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

In table 22 long-time records are averaged to January 1, 1936, for temperatures and precipitation at three stations. Average annual evaporation is over 10 times the average annual precipitation and irrigation is an absolute necessity to produce good crops.

TABLE 22.—*Mean annual temperatures and precipitation at Elephant Butte Dam and State College, N. Mex., and El Paso, Tex.*

Station	[illegible]	Temperature (degrees F)					[illegible]	Annual rainfall, in inches		
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
Elephant Butte Dam, N. Mex.	8	73.88	45.66	59.77	109	−2	47	16.89	3.53	9.92
State College, N. Mex.	37	76.14	43.98	60.10	106	−8	50	17.09	3.49	8.58
El Paso, Tex.	[illegible]	[illegible]	50.8	63.7	106		57	18.29	2.22	8.96

Soils

The soils of the valley are almost entirely of alluvial deposit classed as of the Gila series, previously described. The exceptions are numerous small and scattered areas of wind deposit described as Brazito fine sand. Bordering the valley the soils are classed as of the Anthony series. Much of the material in the valley has been carried over long distances by the Rio Grande. The fall of the stream is not great so that very little gravelly material is transported, making the soils of the valley particularly free of very coarse material except along the margins where the Anthony gravelly loam is sometimes carried out into the valley a short distance by local cloudbursts.

The valley soil is extremely variable in texture and in other properties as well. Many factors are responsible for this. The Rio Grande drains a very extended area. In this area there are a number of different types of parent material that contribute to the river burden. Even some of the Spanish names of tributary streams indicate this variability as Rio Puerco (Muddy), Tierra Blanca (White Earth) Creek, and Rio Colorado (Red River). Rio Grande also flows through a territory where the rainfall is very erratic, local areas occasionally being visited by torrential downpours that carry great quantities of soil into the river. The localized character of the rainfall together with the fact that it might come in quantity sufficient to raise the river to flood volume often meant the deposition of a predominant amount of sediment from a particular locality at one time and from an entirely different locality and type of parent material at some other time.

The highly variable flow of the river had a great influence on the texture of the material being deposited at a particular spot. The ever-changing channel of the stream also had a large influence on the character of the deposit. The result on the soils of the valley has been to make it not uncommon to find five or six variations in texture in a 6-foot depth of sample. The action of the river has been largely controlled in recent years by regulating the flow at Elephant Butte Dam. Besides the variability in texture, there are also abrupt and somewhat unaccountable variations in the productivity of the soil in certain places, giving the crop a distinctly nonuniform appearance.

Agricultural Practice

The following discussion, by Dean W. Bloodgood, associate irrigation engineer, Bureau of Agricultural Engineering, describes the agricultural practice followed in raising the principal crops of Mesilla Valley. Mr. Bloodgood for many years was in charge of the irrigation investigations conducted by the Bureau in cooperation with the New Mexico Agricultural Experiment Station at State College.

Although describing practices in Mesilla Valley specifically, the description is generally applicable also

FIGURE 71.—Irrigation of cotton in Mesilla Valley.

FIGURE 72.—Starting an onion crop in Mesilla Valley.

[illegible] method in Rincon and Palomas Valleys and to the important area [illegible] El Paso.

After the completion of the Elephant Butte Dam [illegible] and irrigation conditions changed rapidly. About this time service by the old community ditch systems was discontinued and distribution of water was taken over by the Bureau of Reclamation. By reason of its retention at Elephant Butte the water contained only some fine sand instead of being somewhat heavily laden with silt, as had been the case immemorially. Farmers did not realize the significance of the change until it was noticed that the ground water was rising rapidly. This realization did not come until about 2 years after the completion of the dam. In that interval the ground water rose so fast that it ruined many acres of highly productive land and damaged much property before remedial measures could be made effective.

The condition described was brought about largely by the use of too much water. In former days when silty water was used the irrigation lands or runs were long and small heads of water were used. These small heads of the now-clarified water took several times as long as formerly to reach the lower ends of the plots. Consequently the runs had to be cut shorter and larger heads of water used in order to irrigate the plots effectively. Before this could be accomplished, however, the entire ditch system had to be reconstructed. The main canals were straightened and enlarged for greater capacity. Many new laterals were constructed about this time, the losses from which also contributed to seepage conditions. Farm ditches were also enlarged and straightened, and modern structures were installed to prevent water losses.

The clear water involved a drainage and alkali problem which materially affected the use of water. High fluctuations of the water table prevented growth of the deeper-rooted plants and the accumulation of alkali in the surface soils damaged good fields. In order to leach out the alkali preparatory to bringing the land back into cultivation, large quantities of water were required; and to assist in the alkali reclamation additional drainage facilities were needed. Hence the alkali problem increased the use of water by reason of the reclamation program.

The systems of cost and delivery were changed so that the farmer paid for the amount of water he used instead of a flat rate for all he wanted. He became more careful in its use, and presently began to use less, paying a fixed flat rate an acre for 2 acre-feet and a sliding scale for amounts over that minimum. Water was delivered on a strictly rotation basis and no favoritism was shown; all farmers using water shared it equally.

As much of the alfalfa land was replaced with cotton, the water requirements for the valley decreased, because alfalfa [illegible] used from 1.5 to 3 acre-feet per acre. Hence cotton was an important factor in increasing the duty of water for the Mesilla Valley and its influence is still felt.

Since cotton became an important commercial crop (about 1920) the use of water for other crops has been nearly constant with little change in irrigation requirements and agricultural practices. The acreage of alfalfa and cotton has averaged about the same over a period of years, and as those crops are the largest users of water, the water requirements of the valley do not change very much from year to year.

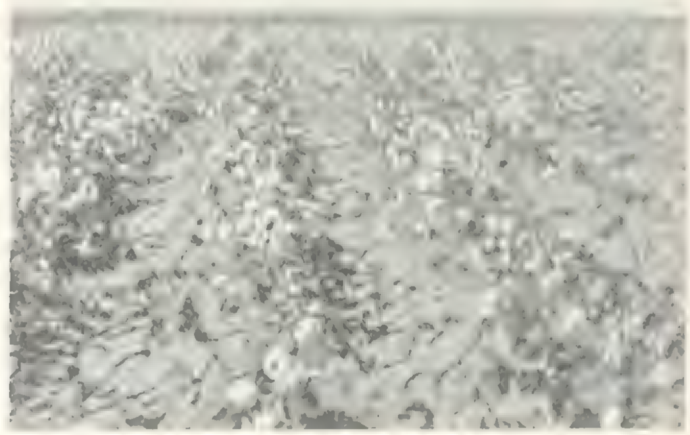
Cotton is usually irrigated by the flooding-border method from May to September, and during this time, four to six irrigations are applied. For good results, 18 to 30 acre-inches of water per acre is used for the heavier soils and 24 to 36 acre-inches for the lighter soils.

The border method of irrigation is almost universally used for the irrigation of alfalfa in Mesilla Valley, where larger heads of water are available and the land is comparatively level with a fairly uniform slope. The fields are divided into strips of lengths varying from a few hundred feet to 800 feet or more, the reason for this irregularity being that the farm boundaries are not on section lines and the farms are irregular in shape. The larger tracts or grants which have been broken up into smaller farms are more regular in shape and easier to farm and irrigate. The width between borders varies from 35 or 40 feet up to 100 feet or more, depending on local conditions. The border between strips of land is usually high enough to keep the water within the borders and from 8 to 10 feet wide, this width, which is flat, permitting economical harvesting. Alfalfa is planted on the borders; hence there is no idle land. The land between the borders is graded level from one to the other so that a head of water will spread across it to a uniform depth.

The use of water by established alfalfa (second year's growth or more) varies from 34 to 60 acre-inches per acre, applied in 8 to 14 irrigations. The average use, as determined from experimental data, is about 48 acre-inches of water per acre. The first year's growth of alfalfa requires more frequent irrigations and possibly a slightly greater amount of water.

The grain fields of Mesilla Valley are generally irrigated immediately after the planting and from then until the crop approaches maturity. Depending upon the season, about four to six irrigations are ordinarily given and from 18 to 24 acre-inches of water per acre is usually applied.

[illegible]



[illegible]

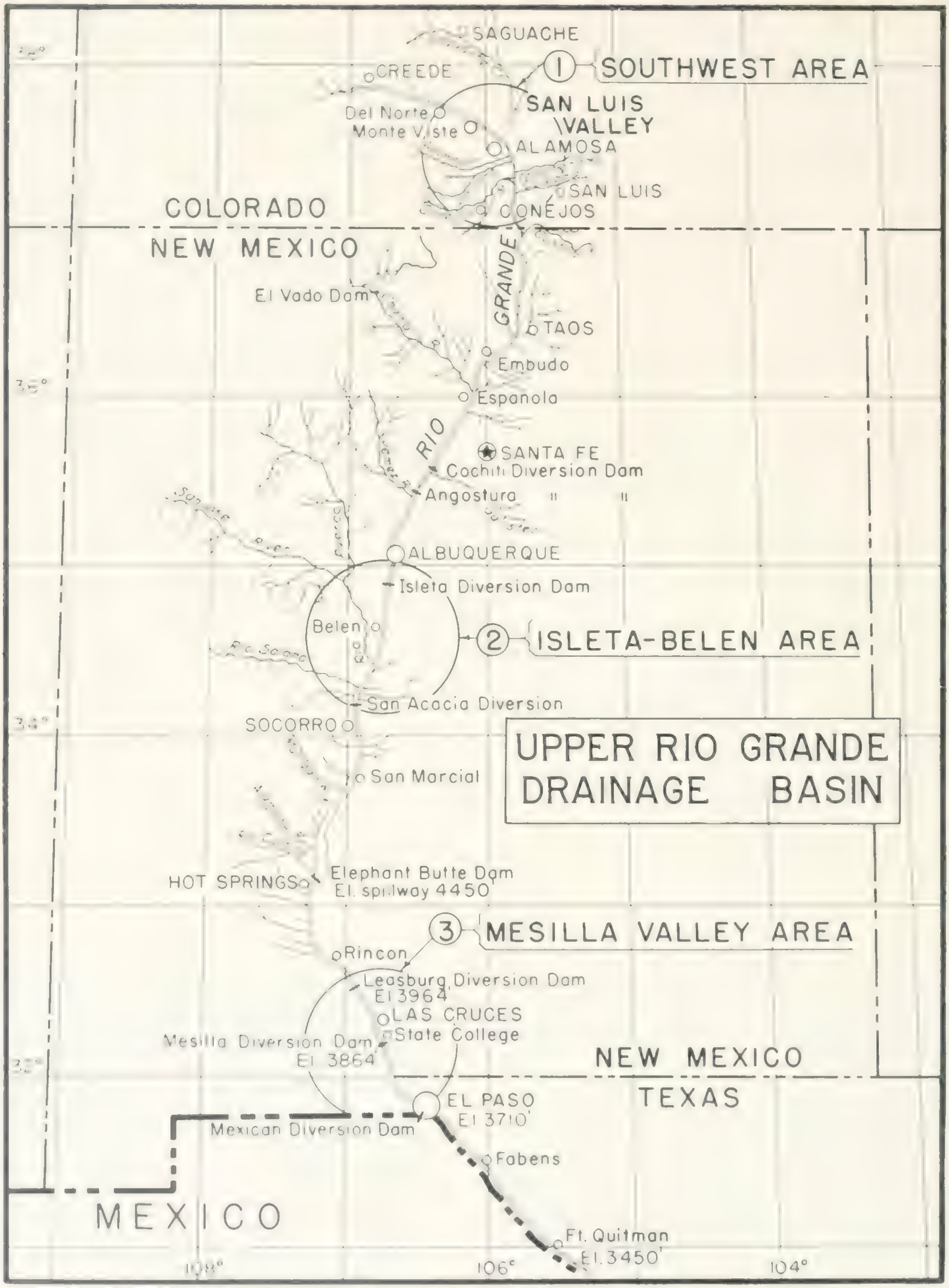
The water requirements for vegetables vary considerably in the amount of water used and frequency of irrigation.

Cabbage is usually irrigated from the middle of March to the latter part of June, and from 18 to 24 acre-inches of water per acre is applied in 10 to 12 irrigations.

The irrigation season for chile and tomatoes is from the middle of May to the middle of September. From 24 to 30 acre-inches of water per acre is applied in 12 to 14 irrigations.

Potatoes have an irrigation season extending from [illegible] to June 30. During this time [illegible] acre-inches of water per acre is applied in [illegible] to 7 irrigations.

Cantaloupes are usually planted about the middle of May, and the irrigation season extends to about August 10. During this time about 20 to 30 acre-inches of water per acre is applied in 8 to 10 irrigations.


SAGUACHE
CREEDE
① SOUTHWEST AREA
SAN LUIS VALLEY
Del Norte
Monte Viste
ALAMOSA
SAN LUIS
COLORADO
CONEJOS
NEW MEXICO
RIO GRANDE
El Vado Dam
TAOS
Embudo
Espanola
SANTA FE
Cochiti Diversion Dam
Angostura
ALBUQUERQUE
Isleta Diversion Dam
Belen
② ISLETA-BELEN AREA
San Acacia Diversion
SOCORRO
UPPER RIO GRANDE DRAINAGE BASIN
San Marcial
HOT SPRINGS
Elephant Butte Dam
El. spillway 4450'
③ MESILLA VALLEY AREA
Rincon
Leasburg Diversion Dam
El 3964'
LAS CRUCES
State College
Mesilla Diversion Dam
El 3864
NEW MEXICO
TEXAS
EL PASO
El 3710'
Mexican Diversion Dam
Fabens
MEXICO
Ft. Quitman
El. 3450'
35°
34°
108°
106°
104°

PART III

SECTION 3.—PREVIOUS STUDIES OF CONSUMPTIVE USE OF WATER

The waters of the Rio Grande above Fort Quitman are largely consumed by native vegetation and irrigated agricultural crops in Colorado, New Mexico, Texas, and Mexico. In the usual year, only a small portion of the total water production of the Upper Rio Grande Basin escapes from it unconsumed, and that small part consists mostly of unusable return flow and flood-peak flows originating below Elephant Butte Reservoir (pl. 1).

The precipitation on the mountain watershed above the San Luis Valley contributes a large portion of the annual water yield of the upper river basin. Therefore, the amount of water available each year for irrigation in the Middle Rio Grande Valley depends in part on the amount consumed in San Luis Valley; and likewise the amount available to Mesilla Valley and other areas below Elephant Butte Reservoir depends in part on the amount consumed both in San Luis Valley and Middle Rio Grande Valley.

This chapter consists of a review of previous studies by various investigators of the consumptive use of water in the San Luis Valley, Middle Rio Grande Valley, and Mesilla Valley. A report on the studies made by the Bureau of Agricultural Engineering during 1936 follows in section 4. The Bureau's investigation was divided into two parts: (1) Consumptive use of water studies on large representative areas (see fig. 75); (2) evapo-transpiration measurements by means of tank and soil moisture experiments.

One of the main objectives of the irrigation experimental work of the United States Department of Agriculture and the agricultural experiment stations of the Western States during more than one-third of a century just past, has been to find the net water requirements and the irrigation requirements of various crops under different climatic and soil conditions. The terms "net water requirements" and "consumptive use in a basic sense", though probably not identical in meaning, are very closely related. A review of the literature on net water requirements is beyond the scope of this report; suffice it to say that many of the references herein to published writings, concern this important topic. Noteworthy among these are the following: (7), (8), (14), (21), (22), (23), (24), (33), and (84).

Some Interpretations of "Consumptive Use"

Most writings concerning the consumptive use of water are in the form of unpublished engineering reports. Among the very few published writings dealing directly with the consumptive use, a report of a committee of the American Society of Civil Engineers entitled "Consumptive Use of Water in Irrigation" (25) is noteworthy.

The committee proposed certain definitions for consumptive use of water in a basic sense, and for the farm, the project, and the valley. It also reviewed previous estimates of consumptive use for large river systems and made citations to 24 articles, published and unpublished dealing with net water requirements and consumptive use.

One of the definitions suggested by the committee of the American Society of Civil Engineers (25) follows:

Consumptive Use in a Basic Sense.—The consumptive use, U, is here defined as the quantity of water, in acre-feet per cropped acre per year, absorbed by a crop and transpired or used directly in the building of plant tissue, together with that evaporated from the crop-producing land.

The Bureau of Agricultural Engineering in a report on Rainfall Penetration and Consumptive Use of Water (4) defines "consumptive use" as "the sum of water used by the vegetative growth of a given area in transpiration or building of plant tissue and that evaporated from that area."

The committee on "absorption and transpiration" of the hydrology section, American Geophysical Union, has proposed the following definition: (47)

Consumptive use.—The quantity of water per annum used by either cropped or natural vegetation in transpiration or in the building of plant-tissue, together with water evaporated from the adjacent soil, snow, or from intercepted precipitation. It is sometimes termed "Evapo-transpiration."

The definition offered by the American Society of Civil Engineers is silent concerning the area involved, therefore implying that the area from which consumptive use occurs is coincident with and equal to the area covered by "cropped and natural vegetation." For experimental studies of consumptive use of water by the use of tanks or of small field plots, the foregoing

definitions are sound and adequate. However, for large tracts of land and entire valleys which include appreciable areas of bare land, native vegetation and of water surfaces, these definitions need to be amplified.

The definition of the "consumptive use of water in a basic sense" proposed by the society committee is in harmony with the basic concept of the Bureau of Agricultural Engineering in the Rio Grande studies. Amplifications have been made in this report in the application of the basic definition to the consumptive use on a large tract of land or in an entire valley.

Bureau of Agricultural Engineering Definitions

As a general definition of consumptive use applied to the Rio Grande Basin problem, the following definitions have been adopted by the Bureau of Agricultural Engineering:

Consumptive use (*evapo-transpiration*).—The sum of the volumes of water used by the vegetative growth of a given area in transpiration or building of plant tissue and that evaporated from adjacent soil, snow, or intercepted precipitation on the area in any specified time. If the unit of time is small, such as a day or a week, the consumptive use is expressed in acre-inches per acre or depth in inches, whereas, if the unit of time is large, such as a crop growing season or a 12-month year, the consumptive use is expressed as acre-feet per acre or depth in feet.

Valley consumptive use.—The sum of the volumes of water absorbed by and transpired from crops and native vegetation and lands upon which they grow, and evaporated from bare land and water surfaces in the valley; all amounts measured in acre-feet per 12-month year on the respective areas within the exterior boundaries of the valley.[1]

As defined by the Bureau of Agricultural Engineering, the valley consumptive use (K) is equal to the amount of water that flows into the valley during a 12-month year (I) plus the yearly precipitation on the valley floor or project area (P) plus the water in ground storage[2] at the beginning of the year (G_s) minus the amount of water in ground storage at the end of the year (G_e) minus the yearly outflow (R); all amounts measured in acre-feet. The consumptive use of water per acre of irrigated land is equal to (K) divided by irrigated area (A_i); and consumptive use per acre of entire valley floor is equal to (K) divided by entire valley area. The unit is expressed in acre-feet per acre or depth in feet.[3]

It has been considered essential, because of extending the definition of the society committee to include the 12-month year, and also in order to analyze the Rio Grande problem in sufficient detail, to introduce and use a new set of symbols. For instance, the symbol K is used to represent the consumptive use in acre-feet on an entire tract or valley; K_c, the consumptive use by crops; and K_n, the consumptive use by native vegetation.

Stream-flow depletion.—The amount of water which annually flows into a valley, or onto a particular land area (I), minus the amount which flows out of the valley or off from the particular land area (R) is designated "stream-flow depletion" (I–R) and is usually less than the consumptive use and is distinguished from consumptive use in the Rio Grande studies.

Résumé of Previous Studies

The following résumé relating to previous studies of consumptive use in Rio Grande Basin is designed to give only a general view of the work done and to designate the public agencies which did it. It is not an exhaustive list of efforts to estimate consumptive use; rather it lists only the more comprehensive research efforts and sources of experimental data on the problem.

The first noteworthy investigation of the effect of irrigation in Colorado on stream flow in the lower valleys was that made by W. W. Follett in 1896 (20). He concluded that irrigation in San Luis Valley had substantially decreased the annual yield of the river in the lower valleys. Follett estimated the use of water from 1880 to 1896 and made "allowances of water per acre" on "irrigated land" along the Rio Grande above El Paso. His allowance (or annual use) in San Luis Valley varied from 0.7 to 4 acre-feet per acre; in the Middle Rio Grande Valley from 1 to 4 acre-feet per acre; and in the Mesilla Valley from 1.5 to 4 acre-feet per acre. Referring to these allowances he asserts:

> * * * [illegible] each year is not supposed to be all actually applied to the beneficial irrigation of a growing crop, but it is intended to show the approximate amount diverted by the ditches and lost to the drainage, being either dissipated by evaporation or by transpiration through the growing crops, or held in the soil but not [illegible]

[1] [illegible]

[2] [illegible] therefore this item has been neglected. (See equation 4, p. 347.)

[3] [illegible] previous studies.

In cooperation with the Colorado Agricultural Experiment Station and the Costilla Estates Development Co., the Bureau of Agricultural Engineering conducted irrigation experiments in San Luis Valley on three tracts near San Acacio, Colo., in 1912, 1913, and 1914. The amounts of water used each month and during the irrigation season were measured for different types of soil producing alfalfa, the grains, beets, peas, and potatoes (24).

The Bureau of Agricultural Engineering, in cooperation with New Mexico Agricultural Experiment Station, studied the water requirements of many crops in Mesilla Valley and ground-water fluctuations in Middle Rio Grande and Mesilla Valleys. Results of these studies, which continued from 1905 to 1930, were published by the New Mexico Agricultural Experiment Station (5), (6), (7), (8), (61), and the United States Department of Agriculture (24).

The Rio Grande project of the Bureau of Reclamation has gathered the data necessary for consumptive use estimates in Mesilla Valley each year since 1919. Bureau of Reclamation engineers have also made estimates of consumptive use in the Middle Valley (12), (17), (18), based on a 2-year study (1927–28). Data collected by the Bureau are reviewed in some detail at a later place in this report in the discussion of consumptive use for each of the valleys.

In 1919 Conkling and Debler (12) in a study of water supply, irrigation, and drainage on the Rio Grande gave particular attention to the consumptive use of water, although of necessity they made many assumptions. That they considered the study of consumptive use of special importance is clearly evident in their statement which follows:

> There is also a paucity of data on consumption of irrigation water. The basis of the entire report is the consumption of water. Not only does the supply for the Rio Grande project depend on the consumption in the Middle Rio Grande and the San Luis Valley but on each project conditions are favorable for re-use of return flow by the acreage on the lower end.
>
> Although there is a lack of extensive data concerning consumptive use in field conditions, yet such as do exist point to a much greater uniformity for this than for diversions. That is, consumptive use with any ordinary economical method of irrigation appears to be independent of diversion. Above a certain amount, sufficient to supply consumption, each acre-foot diverted will, if drainage is perfect and water does not stand on the surface, cause an additional acre-foot of return flow.

From 1922 to 1928 the Colorado State engineer's office made many studies of Rio Grande irrigation problems (36 to 44).

During 1925 and 1926 that office made extensive land surveys looking to the determination of consumptive use of water in certain parts of San Luis Valley, and in 1930 it completed a report of the consumptive use in the major valley divisions (67). From 1930 to 1932, inclusive, it conducted experiments on a tract of some 17,300 acres for the special purpose of finding the consumptive use (70), (71), (72).

In 1915 the Colorado Agricultural Experiment Station published a bulletin based on its cooperative work with the United States Department of Agriculture during the years 1912, 1913, and 1914 (11). It conducted climatic studies also, the results of which were published in 1917 (53).

During the period 1924 to 1932 the State engineer's office of New Mexico and the Rio Grande Valley Survey Commission conducted survey work in the Upper Rio Grande Basin relating to net irrigated areas and consumptive use of water (26), (27), (32), (49), (50), (51), (52), (78), (79).

New Mexico Agricultural Experiment Station, in cooperation with the Bureau of Agricultural Engineering, has done much experimental work on the net duty of water. Most of the results of these studies have been published by the station (7), (8), (61). Some are used in this report as a basis for estimating the consumptive use.

Results of studies of the various phases of the Rio Grande irrigation problems by the Bureau of Reclamation and by the State engineer's offices are presented largely in unpublished engineering reports. Most of the engineering reports include discussions on water requirements which are of necessity based largely on assumptions as to the consumptive use of water in the different valleys. Brief reference is here made to some of the noteworthy reports and their authors, and also to the variability in consumptive use estimates.

In addition to the Conkling-Debler report (1919) hereinbefore mentioned, R. I. Meeker, consulting engineer for Colorado, in a series of reports from 1922 to 1930 (36 to 45) made numerous computations based on assumed values of consumptive use; R. J. Tipton, special engineer for the State of Colorado, made many reports from 1924 to 1935 (65 to 69) relating to Rio Grande water problems and most of them include consumptive use estimates and analyses. E. B. Debler, Bureau of Reclamation hydraulic engineer, has done much work relating to consumptive use in the Rio Grande Upper Basin as evidenced in his reports of 1924, 1927, and 1932 (15, 17, 18); Charles R. Hedke, engineer for New Mexico, made a special report on consumptive use in 1924 (26); E. P. Osgood, engineer for New Mexico and Texas, considered it in 1928 (50 to 52); R. G. Hosea, New Mexico engineer, made brief reference in 1928 (32) to the lack of reliable data, and later in the water requirement studies of Middle Valley (9) he made extended application of consumptive use estimates based on comparisons with Mesilla Valley data. A. W. New-

comer (49), D. C. Henny (30) and others also recognized the importance of consumptive use data. Herbert W. Yeo and R. F. Black (86) in 1931 made a 3-volume confidential report for New Mexico based on E. P. Osgood's San Luis Valley work of 1927–28. Consumptive use is given prominent consideration in the Yeo-Black report.

There is considerable variability in the estimates made by engineers and others for unit values of consumptive use in each of the three major valleys. This is not unusual. It is difficult to make precise estimates because there are so many variable factors influencing the consumptive use. However, some variability in estimates is attributable to lack of specific definitions.

San Luis Valley

[illegible] of consumptive use as defined by the Bureau of Agricultural Engineering to include annual precipitation and draft on ground-water supplies. (See p. 326.)

However, for the San Luis Valley, there seem to be two types of estimates—one being those estimates that have been based on comparative data from other localities, and the other, those based on direct measurements of inflow, outflow, and precipitation in the valley, which in substance accord with the Bureau of Agricultural Engineering (inflow-outflow) method A. (See p. 345.) Most of the estimates based on comparisons with other valleys were made in the earlier years, and the estimates based on direct measurements during the later years, with but little overlapping.

[illegible] study of consumptive use of water; therefore the following estimates for San Luis Valley are presented as nearly as practicable in the order of the time when they were made.

A condensed outline of the plan and order of presentation follows: (1) Early estimates by engineers, based largely on comparisons of the Valley conditions with other valleys in which stream-flow depletion measurements had previously been made. (2) Estimates based on measurements of inflow and outflow, and in some cases also on precipitation, thus applying method A.

Early Estimates by Engineers

Most of the early estimates of "consumptive use" for San Luis Valley are really estimates of stream-flow [illegible] When given in acre-feet per year per acre of irrigated land, they are considered in this report as unit irrigated area stream-flow depletion, i. e., $\left(\frac{I-R}{A}\right)$.[5]

The annual precipitation (P) and the change in the amount of gravitational ground water (G_s-G_e) are usually not included for San Luis Valley. Therefore, in reality, the quantity which is usually reported is $\frac{I-R}{A}$.

It should be observed, however, that $I-R$ (stream-flow depletion) results in part from consumptive use by crops, and in part by native vegetation, together with evaporation from water surfaces and from bare land surfaces. In valleys in which the ratio of irrigated area to the total area (A) is small, say two-thirds or less, it may be misleading to debit ($I-R$) to irrigated area alone, especially if the valley water surface and native vegetation areas are large.

Estimates made by engineers heretofore are reported as acre-feet per acre irrigated in terms of stream-flow depletion regardless of rainfall, that is $\frac{I-R}{A}$, and also as stream-flow depletion plus the annual rainfall divided by the irrigated area, or as $\frac{I+P-R}{A}$. In attempting comparisons of past estimates, special effort is necessary to see that the estimates are comparable.

Conkling-Debler.—In 1919 Conkling and Debler, Bureau of Reclamation engineers, on the basis of results of 2 years' observations of consumptive use in the Boise Valley, Idaho, and 9 years in the Cache La Poudre Valley, Colo., estimated the "beneficial consumptive use" in San Luis Valley, exclusive of rainfall, at about 1.25 acre-feet per irrigated area; for the mountain valleys tributary to San Luis they placed the estimate at 1.0. They found the stream-flow depletion to be 1,041,000 acre-feet per year, of which they estimated 460,000 acre-feet was beneficial consumptive use. The balance was considered as wasted evaporation (12).

Meeker.—R. I. Meeker first made an estimate for the San Luis Valley in May 1924 (37) of 0.9 acre-foot per irrigated acre of drained lands.

In August 1924 (38) he estimated the unit stream-flow depletion as 2.1 excluding rainfall, and attributed the high value to incomplete drainage in parts of the Valley.

In June 1926 (40) he estimated the San Luis Valley stream-flow depletion as 2 acre-feet per acre of irrigated land.

[illegible]

[illegible]

In 1928 (43) he wrote that the beneficial consumptive use in San Luis Valley should be about [illegible] acre-foot per acre of irrigated land.

Large Area Studies

In the past studies of "consumptive use" of water in San Luis Valley different tracts of land have been used. A brief description of four of the tracts is given in the following paragraphs:

1. R. J. Tipton's measurements for the [illegible] area, the southwest area minus Conejos Basin, [illegible] for the years 1921 to 1929. (Data from Tipton's 1930 confidential report (67), Appendix I, tables 3 and 11. Inflow and outflow data based on Colorado State measurements [illegible] by Tipton in 1925 and 1926 under direction of Meeker.)

2. Tipton-Hart experiments on Bowen-Carmel area of some 17,300 acres of which the "average area irrigated" is 12,760 acres. (Data from three Tipton-Hart reports (70), (71), (72), 1930, 1931, and 1932.)

3. Yeo-Black report (86) regarding tracts in water districts 20, 21, 22, and 26 and for the entire valley. (Inflow and outflow data largely from water commissioners records as quoted by Osgood. Areas irrigated based on Osgood's 1927–28 surveys.)

4. Hedke-Bliss entire valley estimates for the 24-year period 1900–1923, inclusive. (Inflow and outflow data from Hedke's January 1925 report (27). Irrigated areas based on surveys of Osgood, 1927–28; Bliss, 1932; and Dallas, 1934. The results of their surveys were used by J. H. Bliss, August 1936, to find a correction factor for the Colorado water commissioners' area figures.)

Tipton.—Extensive and detailed estimates of past "consumptive use" of water in three major divisions of the San Luis Valley were made by R. J. Tipton in his report dated March 1930 (67). These estimates are based on details of water inflow and outflow measurements together with measurements of irrigated areas which are reported fully in tables and illustrated in part in graphs. The report was made for the State engineer of Colorado, and was of a confidential nature. References to it in the following paragraphs and pages of this report are made solely upon the responsibility of the Bureau of Agricultural Engineering, the State engineer of Colorado reserving the right to revise and correct the data as later study and experimentation may require.

Tipton concludes that the "consumptive use" in parts of the San Luis Valley—notably in the Conejos area—is appreciably higher than it would be if water were held in storage reservoirs until late season when needed, rather than applied in excessive amounts during April and May to effect storage in the soil in an attempt to alleviate shortages during July and August.

Measurement of areas of land actually irrigated is vital to the accuracy and the reliability of estimates of stream-flow depletion in terms of acre-feet per acre. As had been shown in preceding parts of this report, areas reported by the water commissioners of divison no. 3 may be appreciably higher than the actual areas irrigated. Tipton says (66) that the water commissioners' reports are invariably high, because the tendency of the farmer is to report a high acreage in order to get a maximum of water.

The special field surveys of irrigated areas in San Luis Valley by Tipton in 1925–26 under the direction of R. I. Meeker are the first such surveys in San Luis Valley of which the Bureau is informed. They appear to be more accurate and reliable than the water commissioners' estimates. He found the total irrigated area for the Valley to be 494,200 acres, which is 80 percent of the 621,836 acres reported by the water commissioners for 1925, and 76 percent of the 653,564 acres reported for 1926.

Tipton's stream-flow depletion measurements, as reported in 1930, are summarized as tables 23 and 24 and consolidated in table 50.

For the Conejos Basin (table 23), he used a round number of 75,000 acres irrigated, as compared to 71,280 given in his 1935 report (69). Based on the area of 75,000 acres, assumed constant for the years 1921 to 1929, Tipton found the average stream-flow depletion equal to 2.58 acre-feet per acre. The minimum was 1.16 in 1924 and the maximum was 3.22 in 1929—nearly three times the minimum.

Table 24 represents the "southwest area minus the Conejos area" for 1921–29, being 115,890 acres of irrigated land, of which 33,000 acres is drained. It shows that the average stream-flow depletion per irrigated

TABLE 23.—*Water consumption in Conejos Basin, San Luis Valley, Colo.*

Year	[illegible]				Outflow in 1,000 acre-[illegible]			Consumption	
	Cone-[illegible]	[illegible] (Ortiz)	San Antonio (Ortiz)	Total	Conejos mouth	[illegible]	Total	Total 1,000 [illegible]	[illegible] acre in acre-[illegible]
[illegible]	[illegible]	(3)	(4)	(5)	[illegible]	(7)	(8)	(9)	(10)
[illegible]	[illegible]	90	15	[illegible]	154	4	158	207	2.76
[illegible]	311	107	22	[illegible]	254	5	260	180	2.40
[illegible]	392	139	[illegible]	[illegible]	296	10	306	217	2.89
[illegible]	[illegible]	[illegible]	17	399	[illegible]	[illegible]	312	87	1.16
[illegible]	[illegible]	[illegible]	9	318	[illegible]	[illegible]	99	219	2.92
[illegible]	219	98	[illegible]	372	185	[illegible]	[illegible]	181	[illegible]
[illegible]	[illegible]	120	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	241	3.20
[illegible]	[illegible]	73	15	[illegible]	110	[illegible]	[illegible]	165	2.20
[illegible]	[illegible]	101	26	[illegible]	199	[illegible]	207	243	3.22
[illegible]	[illegible]	93	16	315	130	[illegible]	137	178	2.37
1931	[illegible]	37	[illegible]	179	[illegible]	[illegible]	41	138	1.84
1932	[illegible]	[illegible]	[illegible]	540	[illegible]	[illegible]	312	228	[illegible]
1933	[illegible]	73	17	[illegible]	113	7	120	184	2.45
[illegible]	[illegible]	29	3	142	[illegible]	[illegible]	32	110	1.47

[illegible]

NOTES.—Data for the years 1921 to 1929, inclusive, taken from table 11 of R. J. Tipton's 1930 report. The 1929 figures represent nine months only. Data for the [illegible]

acre for the period is 1.92 acre-feet, the minimum 1.05 acre-feet, and the maximum 2.50 acre-feet.

For the north area of 179,170 acres and the same period of years the average stream-flow depletion is 2.06 acre-feet per acre, the minimum 1.87, and the maximum 2.40.

In August 1933, in his "Synopsis of Engineering Report on Interstate Phases of Rio Grande and Proposed 'Sump' Drain and State Line Reservoir", Tipton estimated (68) the "beneficial consumptive use" in the "dead", or closed, area irrigated from the Rio Grande as 1.2 acre-feet per acre, excluding rainfall; and for the portion of the closed area irrigated from streams other than the Rio Grande he estimated the consumptive use as 1.5 acre-feet per acre.

TABLE 24.—*Water consumption in southwest area minus Conejos Basin, San Luis Valley, Colo.*

[illegible] irrigated, of w[illegible] is drained]

Year	[illegible] Grande	[illegible] Creek	[illegible] River	La [illegible] Creek	Rio [illegible] (At Ala-[illegible])	[illegible] drain	Total	Outflow in 1,000 acre-feet	Consumption[2] Total [illegible]	Consumption[2] Per acre [illegible] acre-feet
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	(7)	[illegible]	(9)	(10)	(11)
1921	[illegible]	8	[illegible]	[illegible]	[illegible]	[illegible]	934	[illegible]	221	1.91
[illegible]	191	10	127	[illegible]	375	[illegible]	710	428	282	2.44
[illegible]	136	12	110	28	338	10	[illegible]	400	236	2.04
[illegible]	[illegible]	18	91	23	304	8	[illegible]	119	133	1.05
[illegible]	169	[3] 8	[illegible]	14	156	8	441	[illegible]	[illegible]	1.81
[illegible]	166	[3] 9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	193	1.67
[illegible]	218	[3] [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	289	2.50
[illegible]	163	[3] 8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	193	1.67
[illegible]	215	[3] 12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.15
[illegible]	62	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	241	91	.80
[illegible]	102	1	[illegible]	[illegible]	67	[illegible]	[illegible]	[illegible]	[illegible]	1.09
1932	[illegible]	[illegible]	[illegible]	[illegible]	177	7	[illegible]	[illegible]	[illegible]	2.61
1933	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[2] The equivalent, in this table, of stream-flow depletion.

[illegible]

NOTES.—Data for the years 1921 to 1929, inclusive, taken from table 11 of R. J. Tipton's 1930 report. [illegible] used by Tipton only for the years 1921 to 1929.

Bowen-Carmel area studies.—Tipton-Hart Experiments.—Consumptive use experiments were conducted in the Bowen-Carmel area in San Luis Valley by the State of Colorado under the direction of the State engineer during the years 1930, 1931, and 1932 (70), (71), (72). The field work was done under the immediate supervision of R. J. Tipton, special engineer, reporting to M. C. Hinderlider, State engineer, F. C. Hart, special hydrographer, made the measurements and kept the experimental records. All inflows to and outflows from the Bowen-Carmel tract below the Monte Vista canal and above the Empire canal were measured. Automatic stage registers were maintained except for the smaller ditches in 1930, when staff gages only were used. It is probable that the error of inflow-outflow measurements does not exceed 10 percent.

The area of land actually irrigated in the two consumptive-use experimental tracts was measured with a fair degree of precision in 1930, but in 1931, because of inadequate financial support for the work and considerable variation in use of land caused by the serious drought, there was uncertainty as to the area of land irrigated. More reliable area measurements were made in 1932.

The area included within the exterior boundaries of the experimental tract was 17,300 acres and the irrigated area for each of the 3 years was 13,360, 8,703, and 12,399, respectively, making an average of 11,488 acres irrigated, or 66 percent of the gross area. Measurements of the irrigated area were probably less accurate than the water measurements; nevertheless they are considered reliable and accurate in comparison with the water commissioners' estimates.

Both the Bowen and Carmel lands are well drained. The feeder lines of both drainage systems are of tile, and the lower and outlet lines are open ditches.

Results of these San Luis Valley consumptive use experiments are recited by Tipton and Hart in three annual reports (70, 71, 72), which include many details related to water measurements, climatic data, drain discharges, and monthly amounts of consumptive use. There were no observations of depths to water table; hence the quantity $(G_s - G_e)$ of consumptive use equation 4 (p. 347) cannot be evaluated (70).

The Bowen-Carmel experimental tract is wholly in the "live" area of the Valley. (See fig. 78.) Of the gross area of the experimental tract as measured from the map (17,300 acres), the water surface and bare land areas are considered negligible.[6] Therefore the gross area minus the irrigated area gives approximately the area of native vegetation, namely, 4,540 acres.

Results of Experiments.—A résumé of the results of the 3 years' work is given in table 25.

TABLE 25.—*Résumé of use of water in the Bowen-Carmel area in San Luis Valley for the years 1930, 1931, and 1932, based on Tipton-Hart studies*

Year	Total stream-flow depletion [illegible] acre-feet	[illegible] irri-[illegible] (A_i), acres	Stream-flow depletion [illegible] per acre	Total consumptive use [illegible] acre-feet	Consumptive use in irrigated area [illegible] acre-feet	Consump-[illegible] entire area [illegible] acre-feet
(1)	[illegible]	(3)	(4)	(5)	[illegible]	[illegible]
1930	[illegible]	13,360	1.13	26,252	[illegible]	[illegible]
[illegible]	[illegible],924	8,703	1.25	21,096	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible].87	[3] 21,096	[3] 1.68	[illegible]
[illegible]	23,301	12,399	1.88	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.30	[illegible]

[illegible]

[3] Not included in average.

[6] There is practically no free water surface within the tract, it being bounded on [illegible] feet wide and 18 miles long, shows that the area it occupies is only one-half of 1 percent of the gross area and therefore negligible.

Column 2 shows the net stream-flow depletion; that is, the inflow minus the outflow for the combined Bowen-Carmel areas. Column 3 shows the irrigated area, which in 1930 was measured with a fair degree of accuracy. With reference to this, Tipton and Hart said:

> A cruise was made of the [illegible] in both [illegible]. Most of the tracts were regular and followed land lines, except in the case of some of the pasture lands. All pasture land upon which water was actually used, either waste or direct irrigation, was included in the irrigated acreage, but brush pasture was not, unless there were areas of grass on which water was used, in which cases the acreage of grass was included. A small compass was used for obtaining directions and distances were paced, in making the determination of irregular grass acreage.
>
> Early in the season each farmer was visited and questioned as to the acreage he had planted of the various crops, and other land on which water was being used. The figures thus obtained were subsequently found to be high upon comparison with the areas determined by the cruise.

The 1931 area measurements were less accurate than those of 1930, largely because the extreme dryness of the season complicated the determinations of areas. Concerning the 1931 areas Tipton and Hart said:

> In the determination of the irrigated area, the dryness of the season made an accurate determination of the land irrigated impracticable. As a result, the area irrigated, and the consumptive use also, must lie between two limits. (1) One limit is defined by the area of cropped land, the (2) other by the area of land to which water was known to have been applied.
>
> The values of these two areas were obtained from the individual farmers, and checked against the area determined by the 1930 cruise of irrigated acreage. The crop production, and the acreage, however, were also obtained from the farmers themselves.

Tipton and Hart made the following statement concerning 1932 irrigated areas:

> The crop acreage, area irrigated, and production figures were all gathered from personal interview of the farmers in the area, as limited time and funds made it impracticable to again cruise the area. The acreage irrigated was checked against the cruise of 1930 and the results from 1931 in each individual case, and is considered to be fairly accurate.

For 1931, because of the uncertainty in the measurements of irrigated area, both the 8,703 acres to which water was applied and the cropped area of 12,530 acres are reported in table 25. These areas may be considered as "minimum" and "maximum" for the season. Certainly the stream-flow depletion (column 4), and consumptive use (column 6), based on the maximum area of 1931, are too low because the water used was not enough to mature ordinary crops on this area.

It is believed that the quantities 1.13 and 1.25 of column 4, representing stream-flow depletion per irrigated acre, and the quantities 1.52 and 1.22 of column 7, representing consumptive use per acre in entire area, are lower than the amounts for the area normally essential to satisfactory crop production. Both the years 1930 and 1931 were adverse to crop growth. Concerning 1930, Tipton and Hart wrote as follows:

> The season of 1930 was not normal. The first part of the season was very dry, with high winds and cold nights prevailing. After the middle of July ample water was available due to copious rains. Although the season was not normal, yet, in general, crop production over the area investigated was about normal. * * *
>
> The results of any consumptive-use determination for a single season cannot be considered as conclusive. This is especially true when the season is not a normal one, as was the case in 1930.
>
> The early part of the season was characterized by high winds of sustained duration and cold nights, the last killing frost of the spring occurring on June 23. The weather after that was dry and warm, with considerable wind.
>
> During June and the early part of July the demand for irrigation water far exceeded the supply.

That 1931 was a year of unusual and serious drought is well known. The figures for 1932 are probably more nearly representative of consumptive-use requirements than those for either 1930 or 1931—indeed, more nearly representative than the average results for the 3 years. It is probably conservative to conclude that the average of the 3 years is representative of the minimum use for normal years on the area studied, and that the figures for 1932 are more nearly representative of the maximum. In column 4 the 1930 magnitude of stream-flow depletion per irrigated acre is 80 percent of the average; for the 8,703-acre area of 1931 it is 88 percent, and for the 1932 area it is 132 percent. Perhaps it is not extravagant to say that the average is subject to a variation of plus or minus 20 percent.

Yeo and Black.—In 1931 Herbert W. Yeo, State engineer of New Mexico, assisted by R. F. Black, completed their voluminous report on Water Supply, Irrigation and Drainage in the San Luis Valley and Adjacent Northern Areas (86), which contains many data on "consumptive use" of water in San Luis Valley gathered by E. P. Osgood in 1927–28. Lack of funds in 1929 delayed the completion of the report of Osgood's findings, hence his data were later examined and classified by R. F. Black and transmitted to Herbert W. Yeo, State engineer.

The Yeo and Black report, in addition to containing the results of Osgood's 1927–28 area surveys, included descriptions and discussions of irrigation conditions in each of the Colorado State water districts nos. 20 to 27, inclusive, and 35. For each water district, wherever practical, an estimate of the stream-flow depletion ("consumptive use") was made and details for the bases of the estimates presented. The entire report was of a confidential nature and was not published. References to it in the following paragraphs and pages of this report are made solely upon the responsibility of the Bureau, the State engineer of New Mexico reserving the right to revise and correct the data as later study and experimentation may dictate.

[illegible] that data presented demonstrate an average use, from measured inflow since 1912, of 1.99 acre-feet of water per irrigated acre during the irrigation season and 2.04 acre-feet for the year.

One of their tables shows that for the period 1915 to 1928, inclusive, the minimum stream-flow depletion for water district no. 20 lands was 1.68 acre-feet per acre of land irrigated in 1921. The maximum of 2.43 came in 1916 and again in 1922. For this 14-year period, according to Yeo and Black's table, the average stream-flow depletion for district no. 20 was 2.01 acre-feet per acre of irrigated land.

However, certain corrections of these estimated amounts were made, after which Yeo and Black concluded that a summary of the tabulation showed a mean use of water, or depletion from the stream system, since 1912, amounting to 2.29 acre-feet per acre per year in water district no. 20. This figure did not include water derived from artesian wells.

For district no. 21 data were available to Osgood, Yeo, and Black for the year 1927 only. On the basis of these data and the assumption "that all outflow through Alamosa River is derived from water district no. 20, as calculated in the estimate of depletion in that district", they found that the stream-flow depletion ("consumptive use") was 2.6 acre-feet per acre irrigated per year.

On the basis of Osgood's 1927 field studies the irrigated area in water district no. 22 was taken by Yeo and Black as 76,000 acres. State of Colorado inflow measurements for the years 1921 to 1927 inclusive at the following stations were used (Pl.11):

[illegible]
[illegible]
Los Pinos River above Ortiz.
[illegible]

[illegible]

[illegible]

[illegible] urements and estimates as above for the years 1921 to 1927, was found to be 2.67 acre-feet per acre of irrigated land (86).

[illegible] data on which to estimate the stream-flow depletion in water districts nos. 24 and 25 (86).

For water district no. 26 there was no surface outflow; the inflow was 2.9 acre-feet per irrigated acre, which [illegible]

[illegible] averaged 2.10 acre-feet per acre for 570,000 acres of irrigated land, the area which they assert had been found by Osgood in 1927.[7] The minimum stream-flow depletion was 1.92 acre-feet per irrigated acre and the maximum was 2.30. It should be noted that the area 570,000 acres which was considered constant for the period 1918 to 1927 is 73 percent of the 779,671 acres reported as irrigated in 1927 by the Colorado division engineer for division no. 3. It is 131 percent of the 435,790 acres reported by Colorado division engineer for 1918, and 94 percent of the average irrigated area for the period 1918–27 as reported by Colorado division engineer, namely, 607,970 acres.

Yeo and Black estimated the San Luis Valley area on which water might be applied if available as 1,065,000 acres, and by including all the annual rainfall, estimated as 7 inches average, they found the average consumptive use to be 3.17 acre-feet per irrigated acre.

Yeo and Black concluded their discussion of "consumptive use" for certain parts of San Luis Valley with the following estimates:

[illegible]	[illegible]
[illegible]	
[illegible]	[illegible]
[illegible]	[illegible]

They suggested that with complete drainage for the entire valley the depletion might be reduced to from 1.50 to 1.75 acre-feet per irrigated acre per year.

Other estimates for entire valley.—Efforts have been made by several engineers to estimate, as far as practical, the annual amounts of stream-flow depletion for the entire San Luis Valley both in terms of total acre-feet and acre-feet per acre irrigated. The major difficulty in making these estimates is the fact that not all the tributaries have been measured. Therefore certain assumptions regarding inflow must be made. Another uncertainty is as to the area of land actually irrigated. The outflow from the Valley is of record since 1890 and the measurements of it are considered relatively reliable.

Irrigated Land Surveys.—In 1932 John H. Bliss and Russell Dallas surveyed the irrigated lands of San Luis Valley. They measured distances by automobile and plotted all irrigated lands on township plats having a scale of 1 inch equals 1 mile. On the basis of these surveys Bliss prepared a large map of the valley on a

[illegible]

scale 1 inch equals 2 miles. The map was in five sheets and showed the location and extent of the irrigated lands.

The results of the surveys by Bliss are presented in table 26 which shows areas in eight classifications for each of eight water districts. Columns 2, 3, and 4 show the areas of irrigated land which are cultivated, used for production of wild hay and pasture, respectively. Column 5 gives the total irrigated area for the valley and for each of the water districts. The nonirrigated lands as distributed into five classes by Bliss are shown in columns 6 to 10 and the total of nonirrigated areas is shown in column 11. The grand total of all land areas listed in table 26 is probably less than 40 percent of the area of the valley floor. Bliss did not cover all the nonirrigated valley area but only such part as was necessary to find and map the irrigated land.

Area Résumé.—The results of the Osgood, Bliss, and Dallas surveys are summarized in table 27. From the table it appears that the sum of the area irrigated in 1934, 428,737 acres, plus 70,184 acres irrigated in 1932 but not in 1934 because of water shortage, was 498,921 acres. This total is probably nearly representative of the area that would have been irrigated in 1934 if the water supply had been normal. With this interpretation of the 1934 areas, the average irrigated area for the years 1927, 1932, and 1934 would be 513,733 acres, and the respective irrigated acreages would be 99 percent, 104 percent, and 97 percent of the average. This suggests that the area irrigated during the period 1927 to 1934, as found by the New Mexico engineers, was substantially constant.

TABLE 26.—*San Luis Valley lands classification in 1932 by John H. Bliss*

[illegible]

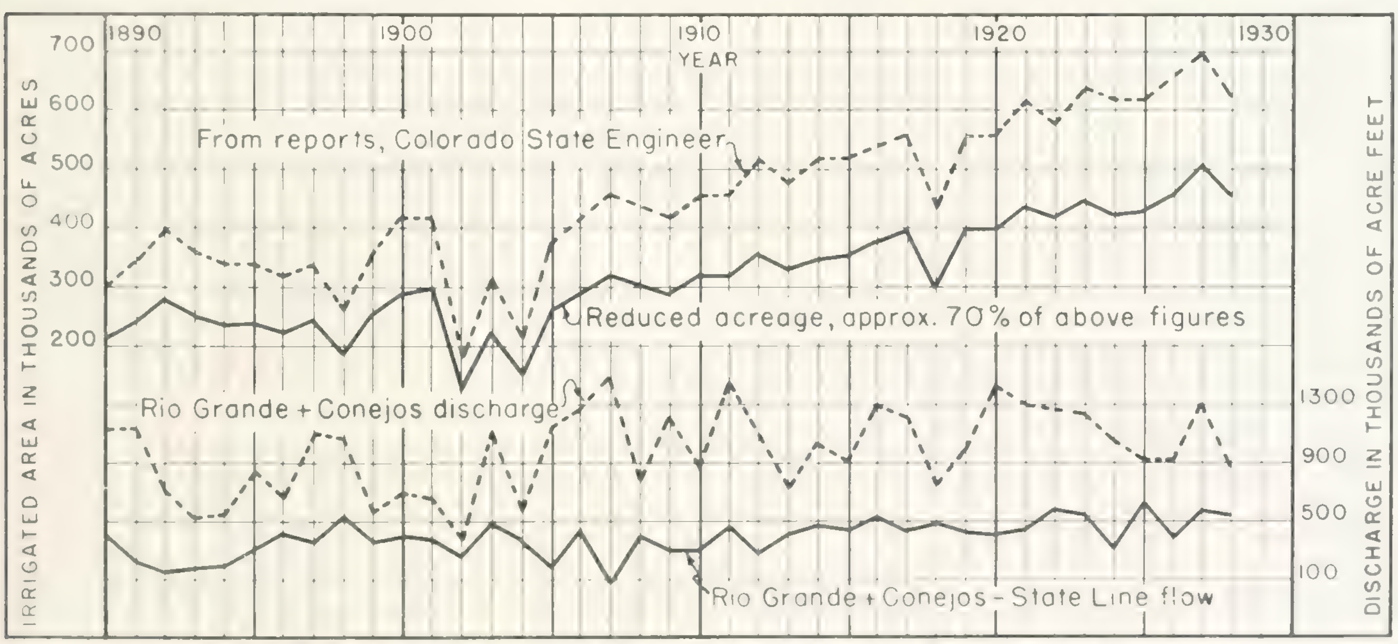
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(1)	[illegible]	[illegible]	(4)	[illegible]	[illegible]	[illegible]	(8)	(9)	[illegible]	(11)
[illegible]	18,051	[illegible]	7,614	72,130	[illegible]		1,698	86	6,331	[illegible]
No. 21	47,627	12,465	4,239	64,331	383	119	3,845		2,516	[illegible]
No. 20	177,677	29,694	27,041	[illegible]	2,582	253	[illegible]	[illegible]	10,232	27,665
[illegible]	[illegible]	6,776	[illegible]	21,023	243	[illegible]	1,338		491	5,028
No. 27	13,252	11,018	[illegible]	35,305		28	6,444			6,472
No. 26	[illegible]	18,514	5,659	30,225	[illegible]	201	7,924		367	8,610
[illegible]	[illegible]	[illegible]	10,104	[illegible]	188	[illegible]	[illegible]	[illegible]	110	3,857
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	3,672
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	304	20,625	70,688

TABLE 27.—*Irrigated area, San Luis Valley, Colo., reported by surveys of Osgood, Bliss, and Dallas*

[illegible]	[illegible]	[illegible]			
		Cultivated	[illegible]	Pasture	Total
[illegible]	1927	328,005	[1] 179,466		507,471
[illegible]	[illegible]	332,319	128,047	74,440	[illegible]
[illegible]	1934	291,278	94,686	[illegible]	428,737
		[2] 9,938	27,222	[illegible]	[illegible]

[1] [illegible]
[2] [illegible]

The irrigated areas reported by the Colorado State engineer for the San Luis Valley as a whole each year from 1890 to 1925 are shown in the upper dotted curve of figure 76. The upper heavy line curve of figure 76 shows 70 percent of the areas reported by the Colorado State engineer.



[illegible]

Valley Stream-flow Depletion.—The Bureau of Agricultural Engineering has endeavored to use stream-flow estimates by Hedke with land area estimates by Osgood and by Bliss, with results briefly shown in the following paragraphs.

The total annual inflow to the valley has been estimated by Charles R. Hedke for New Mexico for the years 1900 to 1923, inclusive (27). His inflow estimates are given in table 28, column 2, and the outflow measurements he reported are in column 3. Column 2 minus column 3 shows that the minimum depletion was 374,500 acre-feet in 1902; the maximum was 1,078,000 acre-feet in 1923, and the average for the 24-year period was 793,800 acre-feet.

On these bases column 6 shows that the minimum per acre stream-flow depletion was 1.82 feet in 1907; the maximum was 4.14 feet in 1903; and the average for the 24-year period was 2.52 feet.

TABLE 28.—*Stream-flow depletion for the years 1900 to 1923, entire San Luis Valley, Colo., based on irrigated area*

Year	[illegible] in 1,000 [illegible]	Outflow [illegible] 1,000 acre-[illegible]	[illegible] flow depletion (I−R) in [illegible] feet	[illegible] in acres	Stream-flow depletion per irrigated acre [illegible] in acre-feet
(1)	(2)	(3)	(4)	[illegible]	[illegible]
[illegible]	[illegible]	301.0	[illegible]	[illegible]	2.42
1901	938.6	284.0	654.6	298	2.20
[illegible]	473.2	98.7	374.5	131	2.86
[illegible]	1,567.0	627.0	940.0	227	4.14
[illegible]	777.2	188.0	[illegible]	[illegible]	3.98
[illegible]	1,660.0	986.0	674.0	265	2.54
[illegible]	1,728.5	842.0	886.5	[illegible]	3.07
[illegible]	2,014.9	1,436.0	578.9	318	1.82
[illegible]	1,053.2	[illegible]	697.2	[illegible]	2.24
[illegible]	1,690.5	[illegible]	757.5	[illegible]	[illegible]
[illegible]	1,187.0	556.0	631.0	326	[illegible]
1911	2,077.4	1,037.0	1,040.4	328	3.17
[illegible]	1,590.5	849.0	741.5	364	2.04
[illegible]	975.0	293.0	682.0	[illegible]	1.99
[illegible]	1,409.6	591.0	[illegible]	369	[illegible]
[illegible]	1,261.8	471.0	[illegible]	379	2.20
[illegible]	1,821.4	[illegible]	1,062.4	[illegible]	2.82
[illegible]	1,670.8	779.0	891.8	393	2.27
[illegible]	1,057.0	263.0	794.0	305	2.60
[illegible]	1,412.8	612.0	[illegible]	391	2.05
[illegible]	2,028.7	[illegible]	987.7	398	2.48
[illegible]	1,678.7	863.0	815.7	[illegible]	1.89
[illegible]	1,724.9	674.0	1,050.9	412	2.55
[illegible]	1,775.2	[illegible]	1,078.2	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

Experimental Studies

Table 29 reports some results of experimental work conducted by the Bureau of Agricultural Engineering and the Colorado Agricultural Experiment Station, in cooperation with the Costilla Estates Development Co., on three tracts near San Acacio, Colo. (24). Each crop was grown on a group of plots, the groups including from 2.1 to 11.1 acres. Three farms were involved in the experiments. The soil of one farm was one of the heavy types of sandy loam, cut up by gravel deposits; the soil of the second was much heavier, in some places almost adobe, with a few gravel deposits and on one side some sand; the soil of the third was sandy.

Tank Experiments

Meeker has given the results of tank experiments near Monte Vista on use of water by meadow grass as follows (43): The consumptive use of water from May

TABLE 29.—*Irrigation water applied monthly, rainfall, and total water received on experimental tracts near San Acacio in San Luis Valley, Colo. (24)*

[illegible]	[illegible]	[illegible]						Total quantity of [illegible]		
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]										
[illegible]	[illegible]	[illegible]		[illegible]		[illegible]		1.35	[illegible]	[illegible]
[illegible]	4	.82	0.31		0.41		0.19	1.73	.49	[illegible]
1913	3	.39	.45		[illegible]			1.43	.49	[illegible]
[illegible]	[illegible]	.62	1.16	[illegible]				2.77	.70	[illegible]
[illegible]	[illegible]	.21		.92	.90			[illegible]	.70	2.73
[illegible]	3	.65		.87	[illegible]			1.97	.70	2.67
[illegible]	[illegible]	1.31	[illegible]	.97				2.89	.70	3.59
[illegible]										
1913	[illegible]	[illegible]	.....	0.44				0.86	[illegible]	1.24
1913	3	.39	0.45	......	0.53			1.37	.38	1.75
[illegible]	3		.59	.42	[illegible]			1.46	.45	[illegible]
[illegible]										
[illegible]	[illegible]	0.51	[illegible]	0.47	[illegible]			[illegible]	[illegible]	[illegible]
1913	[illegible]	[illegible]	[illegible]	.12	0.19			.72	.45	1.17
1913	3	[illegible]	......	.42	.62			1.46	.45	1.91
1914	2	[illegible]	.46	.74				1.20	.70	1.90
1914	[illegible]	[illegible]	.51	.85				1.39	.70	2.09
PEAS										
1913	2	[illegible]	0.42	0.44				[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]		.46				1.07	.49	[illegible]
1913	3	.35	......	.20	[illegible]			.79	[illegible]	1.28
1914	[illegible]		1.02					1.02	.70	1.72
[illegible]	[illegible]		.52	.99				1.51	[illegible]	2.21
PEAS AND BARLEY										
1914	3		1.18	0.71	[illegible]			1.89	0.70	2.59
1914	3	[illegible]	.85	.44	[illegible]	[illegible]	[illegible]	[illegible]	.70	1.99
1914	[illegible]	[illegible]	.52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.73	2.24
PEAS AND OATS										
1913	[illegible]	[illegible]		[illegible]	0.62			[illegible]	0.45	1.91
[illegible]	[illegible]	[illegible]	....	[illegible]	.62			1.46	[illegible]	1.91
[illegible]	[illegible]	[illegible]	1.24	1.05				[illegible]	.70	[illegible]
1914	[illegible]		.89	[illegible]				1.87	.70	2.57
[illegible]	[illegible]		[illegible]	[illegible]				[illegible]	.70	2.29
1914	[illegible]		[illegible]	[illegible]				1.51	.70	2.21
[illegible]										
1913	[illegible]		....	0.27	[illegible]			0.60	0.45	1.05
1913	2	......	0.30		.24	......		[illegible]	[illegible]	.99
[illegible]										
[illegible]	[illegible]	0.43	[illegible]	0.28				[illegible]	0.42	1.13
1913	[illegible]	[illegible]		.80				1.46	[illegible]	1.88
[illegible]	[illegible]	[illegible]		.19	0.19			[illegible]	.49	1.48
[illegible]	3	.42		.42	[illegible]			1.46	.45	1.91
1914	[illegible]	.33		.78				[illegible]	.73	1.81

to October 1927, inclusive, was 1.49 acre-feet per acre, of which 0.67 acre-foot was supplied by precipitation. The depth to water table was about 8 inches during the summer months and 18 inches in October. For the period April 19 to September 14, 1928, the use was 2.17 acre-feet per acre, of which 0.44 acre-foot was precipitation. Two cuttings of hay per year were made and the irrigation season was from about May 1 to September 1.

Tipton and Hart, for the State engineer of Colorado, conducted studies of the use of water by salt grass from tanks, and of evaporation, for several years at Garnett, in San Luis Valley. The results for 1927, 1928, 1930, and 1931 are set out in unpublished reports (70), (71).

The evaporation and transpiration laboratory was established at Garnett in 1927 and continued in 1928. The station was rehabilitated and placed in operation again in April 1930 by Hart. No change was made in the apparatus or in the depth at which the water table was maintained in the various tanks. An additional salt grass tank was installed to maintain the water table at a depth of about 40 inches, but this tank did not begin to function properly until late in the season. Micrometer hook gages were installed on the free water surface tanks. Charles Speiser, United States Weather Bureau observer at Garnett, again was retained as observer. Readings of all apparatus were made two to three times a week. Daily temperature, wind movement, precipitation, evaporation, and evapo-transpiration records were kept.

Tanks nos. 1, 2, 3, and 4 were 3 feet in diameter and 3 feet deep, sunk in the ground nearly flush with the rim and filled with sandy loam soil. The soil was placed in these tanks in the spring of 1927; therefore the soil, together with the vegetation on it, was well stabilized in 1930. Tanks nos. 1, 2, and 3 had a growth of salt grass with water levels maintained at approximate depths of 4, 12, and 24 inches, respectively, and Tank no. 4 held saturated bare soil. The water table was maintained below the surface by means of Mariotte apparatus. Tank no. 4A was similarly installed in 1930 except that it was 4 feet deep with the water level kept at about 40 inches below the surface. Tank no. 5 was 3 feet in diameter and 3 feet deep, sunk in the ground nearly flush with the rim and filled with water. The water level was maintained about 2 inches below the rim. Tank no. 6 was a standard Weather Bureau land pan.

The results of these experiments are summarized in tables 30 and 31. The investigation was divided into two periods, separated by the year 1929 during which no records were obtained. Although the Mariotte apparatus was designed to hold the water table in the soil tanks at constant levels, fluctuations of 2 to 3 inches occurred. Total consumptive use during the growing season is influenced by the depth to water, plants located where water is near the surface showing the greater consumptive use because of more luxuriant growth and increased soil evaporation. Fluctuation of two or three inches is, however, too small noticeably to influence the quantity of water used by the plant.

The effect of differences in predetermined depths is apparent in the salt grass tanks. During the seasons 1927 and 1928 with consumptive use measurements from June to October, inclusive, the average use of water per season, when the water table was 4 to 5 inches below the surface, was 1.57 acre-feet per acre. In the tank having depth to water of approximately 15 inches, the grass used 1.48 acre-feet per acre, and in the tank having a water table at 24 inches the grass used only 1.20 acre-feet per acre. Such tests, however, do not give conclusive evidence of consumptive use at depths greater than those in the soil tanks. The data obtained do not plot as a straight line but as a curve which becomes unreliable when produced to represent depths of more than three feet. During the seasons of 1930 and 1931 consumptive use records were obtained for the period May to October, inclusive, instead of June to October as during the first year of the investigation, and the use of water was consequently greater for the longer season. The increase was partly attributable, however, to the long period (several years) in which the salt grass plants had fully developed their root systems.

Averaging the total use of water during the 4-year period, regardless of the length of season, shows that salt grass in tank no. 1 used 1.78 acre-feet per acre with

[illegible] *water by salt grass and evaporation, Garnett, San Luis Valley,* [illegible]

Month	[illegible] feet per acre), salt grass						[illegible] Soil		Water			
	[illegible] 1		2		3		4		5		6	
	1927	1928	1927	1928	1927	1928	1927	1928	1927	1928	[illegible]	[illegible]
[illegible]		[illegible]		[illegible]		[illegible]		[illegible]		0.32		0.32
[illegible]		.31		.29		[illegible]		[illegible]		.39	.....	[illegible]
[illegible]	0.38	.46	[illegible]	.46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.55	0.49	[illegible]
[illegible]	.32	.53	.33	.44	.23	.42	.37	.53	.44	.47	.45	.52
[illegible]	.33	.36	.34	.29	.29	[illegible]	[illegible]	[illegible]	.35	.42	.34	.44
[illegible]	.25	.23	.27	.19	.22	[illegible]	[illegible]	[illegible]	.29	.33	.28	.34
[illegible]		[illegible]	.17	.10	.11	[illegible]	[illegible]	[illegible]	.22	.27	.22	.27
[illegible]	1.42	1.72	1.49	1.48	1.11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.17
[illegible]	6	[illegible]	15	11	[illegible]	[illegible]	0	0	—	—		

[illegible] original data.

[illegible] original data.

NOTE.—Tanks nos. 1, 2, 3, 4, and 5, 3 feet in diameter and 3 feet deep sunk in ground. Tank no. 6 standard U. S. Weather Bureau land pan.

[illegible]

[illegible]	1930	1931	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1930	1931	1930	1931
[illegible]	[illegible]	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]		0.36		0.35
[illegible]	[illegible]	.30	0.22	.25	0.22	[illegible]		[illegible]	[illegible]	.56	0.52	.47	0.52	[illegible]
[illegible]	[illegible]	.44	[illegible]	.52	.35	.35	-------	.33	.53	[illegible]	.56	[illegible]	.53	.58
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.36	.47		[illegible]	[illegible]	.55	.44	.51	[illegible]	.53
[illegible]	[illegible]	[illegible]	.34	.49	.28	.38		.33	.32	.42	.35	.46	.38	.44
[illegible]	[illegible]	.25	.29	.29	.25	.27	0.12	.25	.31	.32	.35	.33	.33	.33
[illegible]	[illegible]	.15	[illegible]	[illegible]	[illegible]	.12	.11	.12	16	[illegible]	.24	.27	.24	.26
[illegible]		[illegible]		[illegible]		.01		.01		[illegible]		[illegible]		.07
[illegible]	[illegible]	2.02	[illegible]	[illegible]	[illegible]	1.75		1.55	2.28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	25.4	39.1	[illegible]	[illegible]	[illegible]				

[illegible]

[2] Evaporation has been reduced to field conditions by applying coefficient 0.67 to original data.

NOTE.—Tanks nos. 1, 2, 3, 4, 4A, and 5 were 3 feet in diameter and 3 feet deep sunk in ground. Tank no. 6 standard U. S. Weather Bureau land pan.

an average depth of 4.5 inches to the water table. Tank no. 2 consumed 1.74 acre-feet per acre with an average depth of 12.6 inches to water—practically the same as the tank with a higher water level. Tank no. 3 used 1.43 acre-feet per acre, with the water table 24.4 inches below the surface. The slight difference in consumptive use between the first two tanks indicates a nearly uniform use of water for all depths to 15 inches; small differences within this range probably were caused by soil evaporation rather than actual use of water by plant growth.

Middle Rio Grande Valley

There are no complete crop-area records for Middle Valley like the records for Mesilla Valley, but various estimates of consumptive use have been made by engineers, as follows.

Conkling-Debler

Water losses in the Valley and annual water demand are considered in part III of the Conkling-Debler report of 1919 (12), from which the following estimates are taken.

On the basis of a study of available records of flow at Buckman and at San Marcial for the period 1895 to 1918, supplemented by records and estimates of arroyo inflow, the "valley loss" is calculated as 508,400 acre-feet per year, the minimum estimated for the period being 260,000 and the maximum 680,000 acre-feet.

Conkling and Debler point out that these estimates covered a period in which the river was low at San Marcial but it is assumed that if irrigation had been fully restored the losses would have been greater. Their estimate for new conditions after irrigation is extended allows for 15,000 acre-feet of additional loss, making a total of 523,000 acre-feet, exclusive of rainfall.

Land surveys.—The New Mexico State engineer made a preliminary survey of the Middle Valley lands in 1918. His classification of areas and the meaning of each class are quoted by Conkling and Debler (12) as follows:

Land areas.—The total gross area of the valley, as determined by the survey, including all areas from the foot of the mesa as nearly as may be determined, is 206,012 acres, classified as follows:

	Acres
Cultivated (class I)	40,063
Cultivated (class II)	8,732
Alkali and salt grass	51,977
Swamp	6,[illegible]
Timber	37,[illegible]
River and river bed	27,[illegible]
Other valley	33,593
Total	206,012

In cultivated (class I) of this classification is included all areas that are being cultivated and, by a superficial examination, do not show that crops are being impaired by a too high water table. It does not mean that the land is not suffering from a high water table or even endangered, nor that it will grow all crops without injury, but that there are no surface indications of a shallow soil.

In cultivated (class II) are included those cultivated areas which do show indications of a high water table either by evident [illegible]

In alkali and salt grass are included those areas which are not being farmed, have visible quantities of alkali or are overgrown with salt grass. It is usual that such areas have the water table within a very few inches of the surface and during periods of high water table it may be at, or even above, the ground surface.

[illegible] and are indicated by the water surface, marsh and rushes. This [illegible]

two may oscillate to a certain extent with the [illegible] of the ground water within the same year or from year to year.

The timbered areas are those overgrown with timber or brush, usually cottonwoods, willows, or thorn bushes.

In the river and river wash areas are those actually occupied by the river or the washed channels through which the water flows at a higher river stage. These latter are usually free from vegetation and consist of washed sand or gravel.

In the other valley areas are included all lands that do not come under the other classifications and may be sand wastes or sand dunes or sage brush either above or below ditches, and village or town areas.

Integration method estimates.—Table 32, which is taken from the Conkling and Debler report (12), shows the assumed acreages and total use of water for each class of land in the Valley.

TABLE 32.—*Loss in Middle Rio Grande* [1]

[illegible]	[illegible]	[illegible]	[illegible]
Cultivated, class I	[illegible]	[illegible]	[illegible]
Cultivated, class II	[illegible]	[illegible]	[illegible]
Salt grass and alkali	[illegible]	[illegible]	[illegible]
Swamp	[illegible]	[illegible]	[illegible]
Timber	[illegible]	[illegible]	[illegible]
River and river wash	[illegible]	[illegible]	[illegible]
Other valley	[illegible]	[illegible]	[illegible]

[1] After table 25 of the Conkling and Debler report (12).

In a consideration of the water demand for the Valley, Conkling and Debler said:

As the consumptive use is the criterion on this project as in the San Luis Valley, *the actual diversions are quite unimportant so long as the excess over consumptive use does not exceed drainage capacity and cause excessive evaporation from the ground surface.*[8]

[8] Italics by Bureau of Agricultural Engineering

Hedke

In January 1925, Hedke, in his report for the Rio Grande Valley Survey Commission (27), estimated the "present normal stream depletions" as 565,000 acre-feet. His estimates are based on the State engineer's area distribution of the Valley lands into eight classes as reported by Conkling and Debler. However, Hedke used different assumed unit amounts of use for each class of land, with two exceptions.

The details of Hedke's tabulation are reproduced in these pages as table 33, from which it appears that alkali land, swamps, and river bed caused an estimated stream-flow depletion of nearly 330,000 acre-feet. This is 58 percent of the total depletion estimated by Hedke as 565,000 acre-feet.

In his report Hedke says: "The depletion under full development and with drainage, is calculated to be about 500,000 acre-feet,[9] a saving in water of 65,000 acre-feet." The basis of the latter estimate has not been found by the Bureau of Agricultural Engineering. It is noteworthy that Conkling and Debler estimated irrigation expansion would increase the annual use 15,000 acre-feet, where Hedke estimated that under full development and with drainage it would be decreased 65,000 acre-feet per year.

Debler-Elder

On December 15, 1927, E. B. Debler and C. C. Elder, of the Bureau of Reclamation, completed a "Preliminary Report on Middle Rio Grande Investigation—New Mexico"[10] (18), which contains an extended

[9] Conkling and Debler estimated 523,000 acre-feet.

[10] A final report of the Middle Rio Grande investigation was made by E. B. Debler in 1932.

TABLE 33.—*Normal stream-flow depletions with monthly distribution* [1] *Middle Rio Grande Valley, N. Mex., for the year 1925, by classified areas (after Hedke (27))*

	(1)		(2)		(3)		(4)		(5)		(6)		(7)		(8)	
[illegible]	Total, 206,000		Alkali, 52,000		Timber, 37,600		[illegible], 27,500		Cultivated, class 1, 40,100		Swamps, 6,500		Cultivated, class 2, 8,700		Miscellaneous, 33,600	
[illegible]	2.75		3.6		3.1		4.0		2.0		5.0		2.5		0.5	
Depletion, total (acre-feet)	565,000		[illegible]		[illegible]		110,000		80,200		32,500		21,800		16,800	
Month	Percent	1,000 acre-feet	Percent	1,000 acre-feet	Percent	1,000 acre-feet	Percent	1,000 acre-feet	Percent	1,000 acre-feet	Percent	1,000 acre-feet	Percent	1,000 acre-feet	Percent	1,000 acre-feet
January	1.0	7.1	2	3.7	[illegible]	1.2	1	1.1			[illegible]	0.6	1.5	0.3	1.5	0.2
February	3.0	17.4	5	9.4	2	2.3	1	1.1	[illegible]	[illegible]	[illegible]	1.6	3.5	.8	3.5	.6
March	6.0	[illegible]	8	15.0	6	7.0	5	5.5	4	3.2	8	2.6	7.0	[illegible]	7.0	1.2
April	10.0	[illegible]	11	20.6	8	9.3	10	11.0	8	6.4	[illegible]	3.6	9.5	2.1	[illegible]	1.6
May	15.5	88.6	14	26.2	12	14.0	[illegible]	27.5	14	[illegible]	14	4.5	13.0	2.9	13.0	2.2
June	17.0	94.4	14	26.2	[illegible]	16.3	[illegible]	27.5	18	14.4	14	4.6	14.0	3.1	14.0	2.3
July	14.0	[illegible]	[illegible]	22.4	[illegible]	18.6	12	13.2	[illegible]	15.3	[illegible]	3.9	14.0	3.0	14.0	2.4
August	12.0	68.3	[illegible]	18.7	[illegible]	18.6	9	9.9	[illegible]	12.8	[illegible]	3.3	13.0	3.8	13.0	2.2
September	9.0	51.4	[illegible]	[illegible]	[illegible]	14.0	[illegible]	5.5	[illegible]	8.0	[illegible]	2.9	10.5	2.3	10.5	1.8
October	6.5	36.9	7	13.1	8	9.4	4	4.4	[illegible]	4.8	[illegible]	2.3	7.5	1.6	7.5	1.3
November	4.0	21.9	[illegible]	9.4	4	4.6	2	2.2	3	2.4	[illegible]	1.6	4.5	1.0	4.5	.7
December	2.0	9.6	[illegible]	5.6	[illegible]	1.2	1	1.1			[illegible]	1.0	2.0	.4	2.0	.3
Total	100	565.0	[illegible]	187.2	[illegible]	116.5	[illegible]	110.0	100	80.2	[illegible]	32.5	100	[illegible]	100	[illegible]

[1] Monthly distribution based as follows: Columns 3 and 5, thermal consumptive use; columns 2 and 6, free water evaporation; columns 7 and 8, mean of the above 2; column 4, evaporation and quantity. Seasonal distribution: Nonirrigation, 92,000 acre-feet; high water, 238,000 acre-feet; low water, 235,000 acre-feet.

discussion of the water supply for Middle Rio Grande Conservancy District, including estimates of valley stream-flow depletion and consumptive use. On the basis of comparison of the Middle Valley stream-flow depletion with that of Mesilla Valley for the years 1923–25, inclusive, they concluded that, on the whole, the Middle Valley use will be 10 percent higher than the Mesilla Valley use; hence it was estimated that the future irrigation-season use of the Middle Valley would be 570,000 acre-feet.

Debler and Elder contemplated Valley losses under conditions then existing from two aspects, namely, those of (1) stream-flow losses, and (2) experimental determination of evaporation and transpiration losses for typical conditions. They placed their chief reliance on stream loss determinations, preliminary data only being available in December 1927 for the evaporation and transpiration estimates.

Two methods were used to determine Valley losses from stream-flow records: "(a) By an estimate of surface inflow to the Middle Valley from tributaries entering Rio Grande between Buckman and San Marcial with such tributary inflow plus the difference in Rio Grande flow at Buckman and San Marcial representing Valley losses, all by annual amounts, and (b) by estimates of monthly losses based on seepage runs in periods of negligible inflow between Buckman and San Marcial."

The Valley loss according to Debler and Elder is a function of the annual flow at Buckman (18). Their report gives in tabular form estimated losses in Rio Grande discharge from Buckman to San Marcial for the years 1895 to 1926 based on conditions of 1927 and also based on discharges at Buckman. The average for the period is 510,000 acre-feet per year. The year 1904 showed the minimum of 310,000 acre-feet and 1907 the maximum of 694,000 acre-feet. Adding an estimated annual rainfall contribution of 0.71 feet on a valley area of 206,000 acres, equal to 146,000 acre-feet, plus an estimated "gain from deep percolation in the upper portion of the Valley, between Buckman and Bernalillo of 72,000 acre-feet" (subsurface inflow F_t), they estimated the total annual Valley loss to be 728,000 acre-feet.

Expressed in the terms of the Bureau of Agricultural Engineering's equation 1 on page 347 (neglecting capillary storage C_s-C_e and subsurface outflow F_o), the Debler-Elder estimate of 1927 is as follows[11]:

$$K=(G_s-G_e)+(I-R)+F_t+P$$

[illegible]

$$K=O+510,000+72,000+146,000=728,000 \text{ acre-feet}$$

[illegible] 1927 [illegible] conditions. The total annual estimated loss on their bases was 755,900 acre-feet.[12] This is 4 percent higher than the result of the inflow-outflow method computation—728,000 acre-feet. According to Debler and Elder, the difference may represent subsurface (deep percolation) inflow from Bernalillo to San Marcial.

Use of water in the Middle Rio Grande Valley under future conditions of drainage and irrigation was estimated as 570,000 acre-feet for the irrigation season, March to October, in years of normal run-off, when a full irrigation supply is available for diversion. A nonirrigation season return flow correction factor of 35,000 acre-feet, based upon Mesilla Valley experience, was applied, thus making a "net loss from surface waters of 535,000 acre-feet annually." Hence their inflow minus outflow ($I-R$) average of 510,000 acre-feet is only 5 percent lower than the estimate based on Mesilla Valley experience for 3 years.

Hosea

In 1929 then Chief Engineer J. L. Burkholder, of the Middle Rio Grande Conservancy District, submitted to the district's board of commissioners a plan for flood control, drainage, and irrigation, which contained a detailed study of water requirements of the district made by R. G. Hosea under the direction of the late D. C. Henny.

Hosea reported the consumptive use (stream-flow depletion) in Mesilla Valley for the years 1924 to 1928 as 3.1, 3.3, 3.4, 3.5, and 3.8 acre-feet per acre, respectively, the average being 3.42.

Alfalfa and grains are the major Middle Valley crops, whereas cotton (which requires less water than alfalfa) is the dominant crop in Mesilla Valley. Hosea therefore estimated the Middle Valley river depletion requirement as 15 percent higher than that of Mesilla Valley, or 3.9 acre-feet per irrigated acre. On this basis and taking the irrigated area as 123,265 acres, the average annual river depletion of the Middle Valley would be 480,740 acre-feet.

Consumptive use (rainfall deducted) computations made by the integration method on assumed unit amounts for agricultural and other lands, as tabulated by Hosea, are here reproduced as tables 34 and 35, because of their relation to the Bureau of Agricultural Engineering's studies. Table 99 shows that the average crop consumptive use in Mesilla Valley during the 17-year period 1919–35, as estimated by the Bureau of Agricultural Engineering, was 173,082 acre-feet. Dividing this amount by 65,814, the average area of irrigated land, shows a crop consumptive use of 2.63 acre-feet per acre. In table 34 Hosea used an average of 3 acre-feet per acre of irrigated land. Mesilla Valley experience appears to indicate that this is a liberal estimate.

[11] [illegible] $+F_t$ in equation 1.

[12] [illegible]

TABLE 34.—[illegible] Middle Rio Grande Valley, N. Mex.[1]

[illegible]

[illegible]	[illegible]				Total use
	[illegible]	[illegible]	[illegible]	Socorro	
[illegible]	39,000	[illegible]	[illegible]	[illegible]	369,801
Other irrigated lands, 1,200 acres at [illegible]				[illegible]	[illegible]
River channel [illegible]	16,575	[illegible]	[illegible]	22,963	96,868
Excluded areas, 2,757 acres at 2.9 acre-feet				[illegible]	8,000
Rights-of-way, etc., 17,798 acres at [illegible]	3,000	[illegible]	[illegible]	14,016	[illegible]
Total project	[illegible]	154,533	222,987	[illegible]	531,663
Excluded areas between project and San Marcial, 13,385 acres at 2.9 acre-feet					[illegible]
River channel between project and San Marcial, 1,963 acres at 3.9 acre-feet					7,656
El Vado Reservoir evaporation					9,000
Total Valley					587,136
Less drainage return (Socorro division entire year; Cochiti, Albuquerque, and Belen division, November to February					94,849
Net annual consumptive use entire Valley					492,287

[1] After table 30 of Hosea's report (9).

TABLE 35.—*Estimated future losses of water, Middle Rio Grande Valley,*[1] *N. Mex.*

Classification	[illegible] water [illegible] feet	Area in acres	Loss in acre-feet per acre	Total loss in acre-feet per year
[illegible]	6	123,600	3.0	[illegible]
River banks and bars	0–2	18,920	[illegible]	[illegible]
[illegible]	0	10,000	4.6	46,000
Unbenefited area (Pueblito, Bosquecito, [illegible]	[illegible]	2,200	3.0	6,600
Unirrigated:				
Bosque	2–4	5,600	3.6	20,100
[illegible]	1–2	1,500	3.5	5,250
[illegible]	0	70	7.0	500
[illegible]	0	200	1.0	[illegible]
[illegible][2]	[3]	43,910	3.0	131,730
Total for Valley		206,000		653,080
Deduct rainfall of 0.71 inch over 206,000 [illegible]				146,000
Estimated loss				507,080

[1] After table 31 of Hosea's report (9).
[2] Including sand bars, mesa or upland, fallow, unirrigated homesites, road and ditch rights-of-way, areas above ditches and below foot of mesa slopes, etc.
[3] Variable.

Debler (1932)

The results of only one season's work at the Los Griegos Experiment Station (p. 340) were available when the Debler-Elder report was prepared, whereas all the data from that station were used by Debler in his 1932 report (17). The relative maturity of the 1932 report and its direct bearing on the stream-flow depletion and consumptive use problem in the Middle Valley justify liberal reference to it in this report.

Debler again used Mesilla Valley data as a basis of estimating Middle Valley water needs. He gave particular attention to the Mesilla Valley quantity stream-flow depletion plus change in ground-water storage for the years 1926 to 1929, inclusive, and found that it averaged 257,200 acre-feet. The average irrigated area was 75,579 acres. Thus the average consumptive use, excluding precipitation, was 3.40 acre-feet per acre irrigated. As was done in the Debler-Elder report of 1927, 10 percent was added to allow for extra water needs of alfalfa in the Middle Valley, thus making the estimates for Middle Valley 3.74 acre-feet per irrigated acre and 430,500 acre-feet for an irrigated area of 115,000 acres. With the addition of 49,500 acre-feet net losses in river channel, use by salt grass, bosque, swamp, and miscellaneous uses, the total Valley use, exclusive of rainfall, would appear to be 480,000 acre-feet. No allowance was made for arroyo inflow.

TABLE 36.—*Estimated future Valley losses, Middle Rio Grande Valley, N. Mex.*[1]

Classification	Area in [illegible]	Rate of loss in feet [illegible]	Total annual loss in 1,000 acre-feet
Irrigable land:			
Net irrigated	115,000	3.2	368.0
[illegible]	9,475	1.0	9.5
River channel:			
Free water	10,000	4.6	46.0
[illegible]	16,800	3.4	57.1
Non-irrigable areas in excluded tracts [2]	16,142	3.4	54.9
Rights-of-way, towns, roads, flood channels	18,298	3.0	54.9
[illegible][3]	24,285	0.71	17.2
Total	210,000		607.6
Less rainfall	210,000	0.71	149.1
Net use river water	210,000		[illegible]

[1] After table 20 of Debler's 1932 report (17).
[2] Bottom lands excluded as unworthy of development and taken as one-half bosque and one-half salt grass with average water table depths of 3 feet and 1 foot, respectively.
[3] [illegible]

Approaching the problem of estimating future Valley losses by the integration method and assuming unit rates of loss from each of the several classes of land and river water surface, Debler estimated the annual future Middle Valley loss for the 210,000 acres at 607,600 acre-feet. After deducting rainfall he calculated the "net use of river water" at 458,500 acre-feet (table 36).

In applying the integration method Debler used a rate of loss of 3.2 acre-feet for the irrigated land area of 115,000 acres, basing the assumption on a comparison of Middle Rio Grande Valley with the Boise project, Idaho, for which "consumptive use" had been determined by Paul and Steward.

The 1932 report contains detailed data concerning depths to water table, classification of valley land, and estimates of losses based on assumed unit losses for different classes of land and different depths to the water table. The unit loss taken for agricultural lands is again 3.2 acre-feet per acre and it is not varied for different water-table depths. For sand dunes, mesa land, gravel, and embankments, the unit loss is taken

as equal to the annual rainfall. The annual per acre loss used for free water surface is 4.6 acre-feet, for tule swamps 5.6 acre-feet, and for salt grass with water table within 1 foot of the surface, 4.0 acre-feet. (See table 37.)

[illegible] 37.—[illegible]ent *Valley losses, Middle Rio Grande Valley, N. Mex.*[1]

[illegible]	[illegible]	[illegible] table, feet	[illegible] loss, [illegible] year[4]	Total annual loss, 1,000 acre-[illegible]
[illegible]				
[illegible]	10,000	[illegible]	4.6	
[illegible]	[illegible]	[illegible]	3.4	37.2
[illegible]				
[illegible]	1,400	0	4.6	4.6
[illegible]	2,000	[illegible]	5.6	11.2
[illegible]	3,158	[illegible]	[4]0.71	2.2
[illegible]	[illegible]	[illegible]	3.2	[illegible]
[illegible]	2,114	[illegible]	3.2	[illegible]
[illegible]	[illegible]	[illegible]	3.2	19.1
[illegible]	[illegible]	[illegible]	3.2	52.1
[illegible]	17,732	[illegible]	3.2	56.7
[illegible]	[illegible]	[illegible]	3.2	4.3
[illegible]	[illegible]	[illegible]	0.9	1.5
[illegible]	22,778	1 to 2	2.7	61.5
Do.	20,129	[illegible]	1.0	80.5
[illegible]	4,000	[illegible]		18.0
[illegible]	32,821	2 to 4	3.5	114.9
[illegible]	5,000	[illegible]	4.0	20.0
[illegible]				
[illegible]	[illegible]	0	4.6	3.3
[illegible]	[illegible]	[illegible]	5.6	[illegible]
[illegible]	1,210	[illegible]	3.4	[illegible]
[illegible]	275	A. G.[3]	4.0	1.1
[illegible]	[illegible]	Over 6	[4]0.71	3.1
[illegible]	[illegible]	Variable	3.0	[illegible]
[illegible]	182,845			
[illegible]				
[illegible]	2,870	[illegible]	[illegible]	11.3
Total	210,000			[illegible]

[illegible] the year.

[5] Area taken from table 21, 1928 report by Burkholder (9).

On the basis of these estimates and others similar, together with the land classification made by the appraisal section of the conservancy district and the numerous observations of depth to water table (with resulting classification of land areas having water table at different depths), Debler estimated the total annual loss to be 547,200 acre-feet from a 210,000-acre valley area. This is 88.5 percent of the 733,000-acre-feet loss estimated from stream-flow records. Debler says the difference "may be largely accounted for by the approxi- [illegible]"

Résumé

For convenience of reference the estimates by different [illegible] of stream-flow depletion, precipitation and other water losses in the Middle Valley are brought together in table 38. It is evident from the remarks in column 7 that the quantities in column 4 designated $(I-R)$ are not rigorously comparable. However, in spite of the estimated differences between present and future losses the greatest departure of any one estimate from the average of the 10 estimates, namely 505,800 acre-feet, is only 12 percent. Four-fifths of the estimates are within 10 percent of the average. Nevertheless, stream-flow depletion $(I-R)$ for any one year may depart widely from the average. (See Conkling and Debler (12), table 22.)

TABLE 38.—*Résumé of estimates of stream-flow depletion $(I-R)$, precipitation (P), and sub-surface losses (F_s) for the Middle Rio Grande Valley, N. Mex.*

Authority and [illegible] (1)	Method of [illegible] (2)	[illegible] (3)	Estimated amounts in 1,000 acre-feet: $I-R$ (4)	P (5)	F_s (6)	Remarks (7)
Conkling and Debler (1919)	Inflow-outflow.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] time.
	[illegible]		523			[illegible] tions.
	Integration...	Present normal.	[illegible]			Present normal depletion.
[illegible]	[illegible]	Future....	[illegible]			Future.
Debler	Inflow-outflow.	1895–1926.	510	[illegible]	72	
Elder (1927)	Comparison[1]		[illegible]			
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	
Debler (1932)...	Integration...		[illegible]	[illegible]		Future losses.
	[illegible]		[illegible]			Present losses.

[illegible]

[4] Includes 49,500 acre-feet for nonagricultural lands.

Tank Experiments

An experiment station was established by Debler for the Bureau of Reclamation in cooperation with the Middle Rio Grande Conservancy District and the Weather Bureau, in August 1926 near Los Griegos, about 5 miles northwest of Albuquerque, to determine evaporation and transpiration losses (9), (17). The station was located in a salt grass pasture, the soil, vegetation, and surroundings being typical of the low-lying undrained lands of the Valley.

Stock tanks of 4.0 feet diameter were ordered but the actual diameter of pan no. 2 was 48¼ inches and that of all others approximately 45½ inches. Pan no. 1, open water, 2.0 feet deep, was set 1.75 feet in the ground with the water level maintained 3 inches below the rim. A pointed meter gage was fixed in the center of the pan and the water surface was brought to this level daily by adding or removing water with a rated cup. The pan was more nearly like a floating pan than an ordinary ground pan, as the ground-water table was close to the surface, its depth varying from 8 inches to 20 inches during the period of observation.

Pan no. 2, 48 inches diameter, 10 inches deep, was filled to a depth of 8 inches. This was an open water standard Weather Bureau pan mounted on timber [illegible]

tion tape was not available and evaporation was measured in the same manner as with pan no. 1.

Pans nos. 3 to 7 were set in the ground with approximately a 3-inch rim inside and out. The bottom of each was filled with 6 to 8 inches of coarse gravel. Soil was then replaced in pans nos. 4, 5, and 6, which were of 4-foot, 3-foot, and 2-foot depths, respectively, and planted with salt grass sod. Pans nos. 3 and 7, of 4-foot and 2-foot depths, respectively, were filled with river wash material, hauled from a sand bar on the bank of the Rio Grande, composed of rather fine sand with traces of silt. The water table depths in the pans were maintained at predetermined depths by use of Mariotte apparatus, the equipment being similar to that used at the Fort Collins laboratory of the Bureau of Agricultural Engineering.

The results of measurements at the Los Griegos station are shown in tables 39 and 40. Data on soil evaporation and consumptive use by salt grass and tules are given in table 40. There was some difference in water use by salt grass during the 2 years, the greater use occurring during 1927–28. Use by salt grass

TABLE 39.—*Evaporation and meteorological records 1926–28 at Los Griegos station, Middle Rio Grande Valley, N. Mex.*[1]

Period	Evaporation, feet: Ground [illegible]	Evaporation, feet: Weather Bureau pan no. 2	Mean monthly air temperature, [illegible]	Monthly precipitation, inches	[illegible] wind velocity, miles per hour [2]	Relative humidity, [illegible]
[illegible]						
September	[illegible]	0.585	67.2	[illegible]	2.7	59
October	.314	.417	57.3	1.03	2.4	64
November	.240	.336	44.2	[illegible]	3.5	50
December	[3] .075	[illegible]	35.4	[illegible]	2.4	75
1927						
January	[illegible]	.121	38.9	[illegible]	2.0	64
February	[illegible]	.269	44.6	.34	3.6	[illegible]
March	[illegible]	.519	46.5	.50	4.7	[illegible]
April	.476	.697	[illegible]	.17	4.0	45
May	.768	1.103	61.8	[illegible]	4.6	[illegible]
June	.569	.850	67.9	1.00	3.1	45
July	[illegible]	.937	74.7	.80	2.7	[illegible]
August	.555	.760	71.3	1.62	2.5	60
September	[illegible]	.558	66.3	1.34	2.8	62
October to September [illegible]	4.717	6.673	55.2	7.81	3.2	[illegible]
1927						
October	.322	.462	[illegible]	.19	2.2	[illegible]
November	.213	.282	46.6	.04	2.5	55
December	[illegible]	.121	31.5	.06	[illegible]	68
1928						
January	.090	.168	33.5	.00	2.6	[illegible]
February	.158	.242	38.2	.32	3.6	44
March	.359	.514	47.1	.06	3.6	31
April	.500	.718	52.0	.75	5.1	29
May	.445	.676	61.5	1.38	3.3	39
June	.720	1.060	68.5	.00	3.8	22
July	.617	.917	73.5	[illegible]	2.4	43
August	.614	.699	70.2	2.65	2.6	62
September	[illegible]	.511	63.6	.15	2.3	43
October to September [illegible]	4.571	6.470	53.4	7.03	3.1	43.1

[1] Station located ½ mile east of Rio Grande, about 5 miles northwest of Albuquerque, elevation 4,970 feet. Records by E. B. Debler and C. C. Elder, United States Bureau of Reclamation. After table 35 Debler's 1932 report (17).

[2] Anemometer 2 feet above ground surface.

[3] Pans ice-covered during most of December and to Jan. 9, 1927.

appears to be in direct ratio to depth to water table; that is, it plots as a straight line. This becomes more evident as depth to the water table increases and consumptive use decreases. For instance, with the water table at 2 feet in depth, consumptive use was 1.6 acre-feet per acre during the first year, and 2.1 acre-feet per acre during the second year. However, as ground water approached the surface consumptive use increased to nearly 4 acre-feet per acre per year and was practically the same for each year of the investigation.

Debler's estimated losses for the Middle Rio Grande Valley have been previously set forth. (See table 37.)

Lower Valley

Not all the estimates by engineers, of use of water in Mesilla Valley, are strictly comparable with each other. Some include the entire Rio Grande Project, while others are concerned specifically and alone with the Mesilla Valley portion of the project; but they are so closely related as to justify comparisons even though they can be only approximate. However, in addition to the various studies by engineers, investigation of the use of water by crops in Mesilla Valley has been carried on by the New Mexico Agricultural Experiment Station, much of it in cooperation with the Bureau of Agricultural Engineering. Specific references are made to both sources of data in the following paragraphs:

Estimates by Engineers

A few of the Mesilla Valley and related estimates made by engineers representing the different interested States are reviewed below.

Meeker.—In May 1922 Meeker estimated the "ultimate net" consumptive use for the Rio Grande Project (150,000 acres) as 2.5 acre-feet per acre (36), exclusive of river channel or reservoir losses. In August 1924 he estimated that the actual water consumption from San Marcial to Fort Quitman was 5.7 acre-feet per acre of irrigated land (38). The losses and uses were not segregated in the 1924 analysis; hence the estimate is not comparable to those which preceded and followed it.

On June 8, 1926 the same investigator estimated the consumptive use for irrigated land on the Rio Grande Project above El Paso as 2 acre-feet per acre (40). This figure is roughly comparable to the Bureau of Agricultural Engineering's use by crops per acre irrigated (K_c/A_i) for Mesilla Valley, which for the 17-year period 1919–35, as determined by method B, is 2.7 acre-feet per acre of irrigated land.

On June 20, 1928 Meeker analysed the Bureau of Reclamation's records for Mesilla Valley for the years 1923 to 1927 and reported the consumptive use figures given in table 41 (42).

[illegible] *d depth to water table below ground surface, in feet, Los Griegos station, 1926–28, Middle Rio Grande Valley, N. Mex.*[1]

[illegible]	[illegible]				Salt [illegible]								[illegible]
	[illegible] no. 3		[illegible]		Pan [illegible]		Pan no. 5		Pan no. 6		Pan no. 8		Pan no. 9
	Evapo-[illegible]	[illegible]	[illegible]	[illegible] depth	[illegible] ration and transpi-[illegible]	Average depth	Evapo-[illegible] and transpi-ration	Average depth	Evapo-ration [illegible] transpi-[illegible]	Average depth	Evapo-ration and transpi-ration	Average depth	Evapo-ration [illegible] transpi-ration
[illegible]													
[illegible]	0.19	[illegible]	[illegible]	0.37	[illegible]	[illegible]	0.18	1.35	[illegible]	0.48			
November	[illegible]	2.32	[illegible]	.25	[illegible]	2.32	.08	1.15	[illegible]	.40			
[illegible]	.12	[illegible]	[illegible]	.20	.09	[illegible]	[illegible]	[illegible]	[illegible]	.20			
[illegible]													
[illegible]	[illegible]	2.11	.12	.19	.01	[illegible]	.01	1.17	[illegible]	[illegible]			
[illegible]	.10	[illegible]	[illegible]	.35	[illegible]	1.82	.07	1.24	[illegible]	.39			
[illegible]	.17	[illegible]	[illegible]	.28	[illegible]	1.67	.11	1.10	[illegible]	.40			
[illegible]	[illegible]	[illegible]	[illegible]	.45	.01	1.67	.12	1.23	[illegible]	.47			
[illegible]	[illegible]	[illegible]	[illegible]	.41	[illegible]	2.30	.26	1.22	[illegible]	.37			
[illegible]	.16	[illegible]	.57	.36	.23	2.23	[illegible]	1.28	[illegible]	.41			
[illegible]	.11	2.70	[illegible]	.39	.29	2.25	.51	1.27	[illegible]	.41			
[illegible]	[illegible]	2.43	.54	[illegible]	.35	2.28	[illegible]	1.12	[illegible]	.40			
September	[illegible]	2.24	[illegible]	.34	.28	2.30	[illegible]	1.06	[illegible]	.39			
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.51	2.07	[illegible]	1.18	[illegible]	.38			
[illegible]													
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.16	[illegible]	[illegible]	.29	.47	0.04	3.06	[illegible]
November	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.02	.10	1.16	.09	.45	.02	3.08	.15
December	[illegible]	1.59	.11	[illegible]	[illegible]	1.89	.05	1.18	[illegible]	.39	.02	3.10	.08
[illegible]													
[illegible]	[illegible]	2.10	.13	[illegible]	[illegible]	2.17	.01	1.10	.03	.39	.01	3.07	.10
February	[illegible]	2.22	.17	[illegible]	[illegible]	2.17	.03	1.19	.05	.40	.03	[illegible]	.14
March	[illegible]	[illegible]	.35	.31	[illegible]	2.10	.05	1.62	.09	.49	.01	3.04	[illegible]
[illegible]	[illegible]	[illegible]	.43	.31	.10	2.10	.16	1.30	.17	.40	.07	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	.28	[illegible]	2.09	.32	1.30	.40	.42	.13	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	.58	.42	.18	[illegible]	.45	1.41	.74	.53	.02	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	.57	.34	.32	2.33	.60	1.43	[illegible]	.51	.16	3.09	1.09
[illegible]	[illegible]	[illegible]	.47	.25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.28	[illegible]	.89
September	.13	[illegible]	.37	.25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.05	3.07	[illegible]
October to September	1.33	2.07	4.12	.29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.07	[illegible]

[1] [illegible]

TABLE 41.—[illegible], *1923–27*

What the consumptive use includes	Use in acre-feet per cropped acre				
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
River depletion plus annual rain plus arroyo inflow	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
River depletion only	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Meeker recorded his opinion briefly concerning the above amounts of consumptive use as follows: "Some question about accuracy of records at Leasburg: Irrigated area, which is greater than cropped area, should have been used. The above values are too high and higher than they will be in the future when river conditions are stabilized and water economy practiced. A study of consumptive use between Elephant Butte Reservoir and El Paso by Meeker for past 5 years shows a much smaller consumptive use of reservoir water."

Meeker and Burgess.—In November 1928 Meeker and Burgess reported use for irrigated lands from Elephant Butte Reservoir to El Paso (Courchesne Station) for the years 1920 to 1927, inclusive (44). Their estimate, including river evaporation losses, is 3.23 acre-feet based on the "gross area of irrigated land." They considered the average width of river surface as 400 feet, thus making a water surface area of 50 acres per mile, or 7,000 acres of water surface in all. Using 5.35 feet as the average annual water surface evaporation and deducting the annual water surface loss from the river depletion, they found the consumptive use to be 2.68 acre-feet per acre for the gross area of irrigated land, not including rainfall. If 85 percent of the gross area of land were actually irrigated, then the consumptive use based on the net area would be 3.15 acre-feet per acre. For future conditions Meeker and Burgess estimated the average consumptive use from Elephant Butte Reservoir to El Paso as 2.4 acre-feet per "gross acre of irrigated land" exclusive of rainfall, as compared to 2.68 for the years 1920 to 1927. For the area between El Paso and Fort Quitman they found, on the basis of the 5 years 1923 to 1927, after deducting estimated river and evaporation losses of 88,000 acre-feet per year, a consumptive use of 2.8 acre-feet per acre and an estimated future consumptive use of 2.6 acre-feet per gross acre.

Considering Mesilla Valley only, for the 5-year period 1923 to 1927, Meeker and Burgess found a con-

sumptive use of 3.5 acre-feet per acre of irrigated land, exclusive of arroyo inflow and of rainfall (41).

Osgood.—In 1928 E. P. Osgood made a report (52) on the consumptive use of the Rio Grande project from Elephant Butte Reservoir to Fabens, Tex. He seems to have charged all the water loss between Elephant Butte and Fabens against the irrigated land, thus including water losses from water surface and bare land, evaporation losses, and use by native vegetation as consumptive use. His results are roughly comparable, it seems, with the sum of $K_c+K_n+K_f+E_w+E_l$ divided by A_i or, more briefly, to the ratio $I-R/A_i$, provided precipitation and ground water storage are ignored. (See p. 346 for symbols.) The Bureau of Agricultural Engineering's results apply to Mesilla Valley only; whereas the results obtained by Osgood represent the larger area including Rincon Valley, some Mexico lands and parts of El Paso Valley.

Because Osgood's graph (fig. 77) shows the uses below Elephant Butte Reservoir for each month of the year, it is of special interest. During the years 1919 to 1922, as shown in figure 77, the outflow measurements were at Fabens Bridge, Tex., but during the years 1923 to 1927 they were at Fort Quitman. The "consumptive" use at any time is equal to the vertical distance between the plotted flows at that time.

The results of estimates by Osgood appear in table 42. Column 2 shows areas of land irrigated between the Elephant Butte Reservoir and Fabens, Tex.; column 3 shows the stream-flow depletion comparable to the quantity $(I-R)$ as used in this report, and column 4 shows the stream-flow depletion in acre-feet per acre of irrigated land.

For comparison with Mesilla Valley stream-flow depletion during the same period of years, the inflow at Leasburg as given in column 2 of table 92, less the outflow at Courchesne, divided by the irrigated areas, given in column 7 of table 93, are shown in column 5, table 42. It will be noted that stream-flow depletion results by Osgood have an average for 1919 to 1927 inclusive of 4.0 acre-feet per acre as compared to 3.4 for the Mesilla Valley studies by the Bureau of Agricultural Engineering, thus showing an excess of 18 percent in the Osgood estimates.

TABLE 42.—*"Consumptive use" of water estimated by E. P. Osgood for the lands irrigated between Elephant Butte Dam, N. Mex., and Fabens, Tex., with comparisons to Mesilla Valley stream-flow depletion computations by the Bureau of Agricultural Engineering for the years 1919 to 1927*

Year	Elephant Butte to Fabens; area irrigated in acres	Reservoir water consumed, in acre-feet	Elephant Butte to Fabens; "consumptive use" in acre-feet per acre	Mesilla Valley, stream-flow depletion $\left(\frac{I-R}{A_i}\right)$ acre-feet per acre[1]
(1)	(2)	(3)	(4)	(5)
1919	92,238	417,200	4.5	3.4
1920	95,605	491,000	5.1	1.9
1921	97,994	404,700	4.1	[illegible]
1922	98,062	544,100	5.5	4.5
1923	126,958	511,700	4.0	4.8
1924	154,948	629,500	4.1	[illegible]
1925	173,978	547,800	3.2	[illegible]
1926	192,173	494,300	2.6	[illegible]
1927	187,373	656,980	3.5	3.6
Average			4.0	3.4

[1] Column 5 has been computed by the Bureau of Agricultural Engineering on the bases of inflow (I) at Leasburg, outflow (R) at Courchesne, and Mesilla Valley irrigated areas (A_i) as reported by the Bureau of Reclamation.

Records of Use of Water

The Bureau of Reclamation keeps records of water distribution for Rincon, Mesilla, and El Paso Valleys. These include monthly amounts of water diverted, main canal waste, main canal losses, and water delivered to farms. E. B. Debler in a report on use of water on Federal irrigation projects gives a summary of records for the Rio Grande project from 1912 to 1926 inclusive (16).

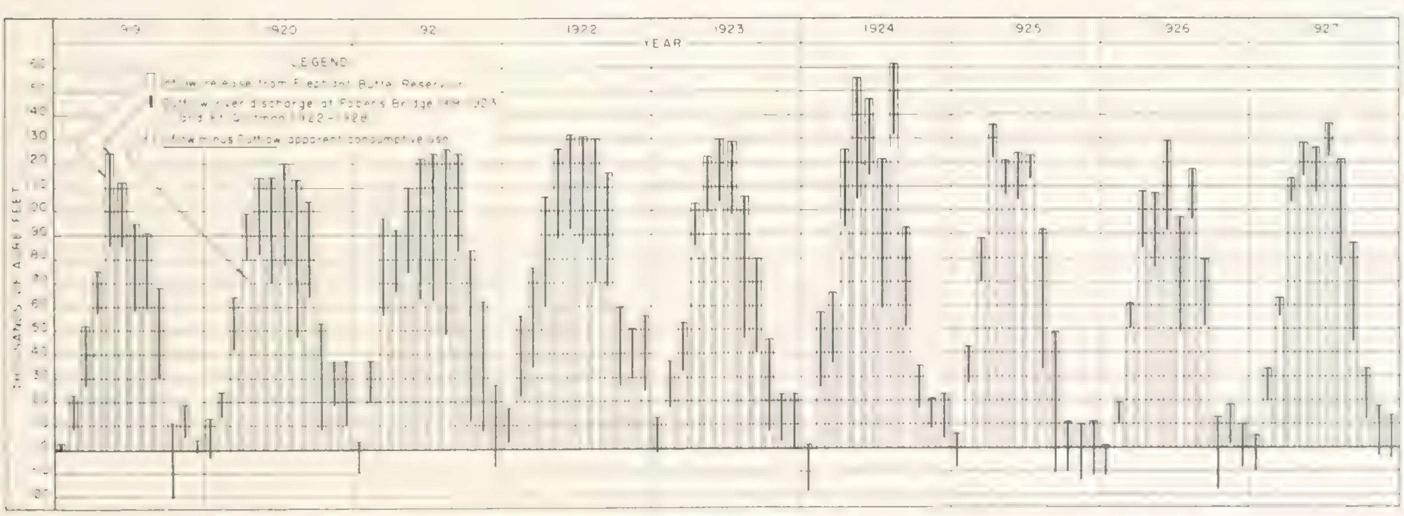


FIGURE 77.—Monthly inflow, outflow, and apparent consumptive use of irrigation water, Rio Grande project. (After E. P. Osgood.)

Experimental Studies

Investigations on the use of water on crops have been conducted by the New Mexico Agricultural Experiment Station and the Bureau of Agricultural Engineering for many years. Some of the results are reproduced in tables 43 and 44, inclusive, from United States Department of Agriculture report (24). Other studies by Dean W. Bloodgood, associate irrigation engineer of the Bureau of Agricultural Engineering, and Albert S. Curry, in charge of irrigation department of the New Mexico Agricultural College, have been published by the college (7), (8), (14).

TABLE 43.—*Irrigation water applied, rainfall, total water received by experimental [illegible]*

[illegible]	[illegible] irri- [illegible]	Irriga- [illegible]	[illegible]	[illegible]		
				[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1905	[illegible]	[illegible]	[illegible]	[illegible]	.82	4.20
1905	3.4	12	[illegible]	[illegible]	[illegible]	[illegible]
1913	24.4	7	[illegible]	[illegible]	[illegible]	3.72
1913	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1913	[illegible]	4	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	21.4	11	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	6.37	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	14.5	[illegible]	do	[illegible]	[illegible]	3.19
1923	.580	13	[illegible]	[illegible]	[illegible]	[illegible]
1923	.581	13	[illegible]	[illegible]	[illegible]	5.38
[illegible]	[illegible]	13	[illegible]	[illegible]	[illegible]	4.47
1923	.499	13	do	[illegible]	[illegible]	[illegible]
1923	.503	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1923	[illegible]	13	do	[illegible]	[illegible]	[illegible]
1923	.338	13	do	[illegible]	[illegible]	[illegible]
1923	.332	13	[illegible]	[illegible]	[illegible]	[illegible]
1923	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1913	[illegible]	[illegible]	[illegible]	1.85	[illegible]	[illegible]
1915	[illegible]	[illegible]	do	2.09	.22	2.31
1915	[illegible]	[illegible]	[illegible]	1.88	.22	2.10
1915	[illegible]	[illegible]	do	2.03	.22	2.25
1915	[illegible]	[illegible]	[illegible]	1.99	.22	2.21
1915	[illegible]	[illegible]	do	2.67	.22	2.89
1915	[illegible]	[illegible]	do	2.77	.22	[illegible]
1915	[illegible]	[illegible]	[illegible]	2.10	.22	2.32
1915	[illegible]	[illegible]	[illegible]	2.39	.22	[illegible]
1915	[illegible]	[illegible]	[illegible]	2.46	.22	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	1.77	.22	1.99
1915	[illegible]	[illegible]	[illegible]	2.67	.44	3.11
1915	[illegible]	[illegible]	[illegible]	2.51	.44	[illegible]
1915	[illegible]	[illegible]	do	2.64	.44	3.08
1915	[illegible]	[illegible]	[illegible]	2.67	.44	3.11
1915	[illegible]	[illegible]	[illegible]	2.68	.44	3.12
[illegible]	[illegible]	[illegible]	[illegible]	2.78	.44	3.22
1915	.29	[illegible]	[illegible]	2.62	.44	3.06
1915	.26	[illegible]	[illegible]	2.46	.44	[illegible]
1915	.29	[illegible]	do	2.58	.44	3.02
1915	.28	[illegible]	[illegible]	2.37	[illegible]	[illegible]
1926	[illegible]	[illegible]	[illegible]	[illegible]	.47	4.47
1926	[illegible]	[illegible]	[illegible]	3.41	.47	[illegible]
1926	[illegible]	[illegible]	do	2.00	.47	[illegible]
1926	[illegible]	[illegible]	[illegible]	[illegible]	.47	[illegible]
1926	[illegible]	[illegible]	do	[illegible]	.47	2.57
1926	[illegible]	[illegible]	do	2.16	.47	2.63
1926	[illegible]	[illegible]	do	[illegible]	.47	2.90
1926	[illegible]	[illegible]	do	2.18	.47	2.65
1926	[illegible]	[illegible]	do	3.52	.47	3.99
1926	[illegible]	[illegible]	[illegible]	3.44	.47	3.91
1926	[illegible]	[illegible]	do	[illegible]	.47	[illegible]
1926	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[1] [illegible]
[2] Plot.

TABLE 44.—*Use of water on alfalfa, water applied at each irrigation, rainfall, total water received in Mesilla Valley, N. Mex.*[1]

[illegible]	Irrigations, number	Depth applied each irrigation, inches	Total quantity of water [illegible]		
			Irrigation, acre-feet	[illegible] acre-feet	Total, acre-feet
[illegible]	12	[illegible]	5.00	0.56	5.56
[illegible]	19	2	3.17	.56	3.73
[illegible]	11	4	4.67	[illegible]	5.23
[illegible]	16	3	4.00	.56	4.56
1916	15	3	3.75	.56	4.31
1916	13	4	4.33	.56	4.89
1916	10	[illegible]	4.17	.56	4.73
1916	18	[illegible]	3.00	.56	[illegible]
1916	[illegible]	4	6.33	.56	6.89
1916	12	[illegible]	5.00	[illegible]	[illegible]
1917	12	5	5.00	.44	5.44
1917	14	[illegible]	3.50	.44	3.94
[illegible]	13	3	3.25	.44	3.69
1917	10	4	3.33	.44	3.77
1917	[illegible]	[illegible]	3.75	.44	4.19
1917	11	4	3.67	.44	[illegible]
1917	10	4	3.33	.44	[illegible]
[illegible]	15	3	3.75	.44	4.19
1917	18	2	[illegible]	.44	3.44
[illegible]	[illegible]	3	[illegible]	[illegible]	4.19
1918	14	3	[illegible]	[illegible]	[illegible]
1918	11	5	4.58	[illegible]	[illegible]
1918	12	4	[illegible]	.29	4.29
[illegible]	17	3	4.25	.29	[illegible]
1918	19	2	3.17	.29	3.46
1918	11	5	4.58	.29	[illegible]
1918	11	4	[illegible]	.29	[illegible]
[illegible]	15	3	3.75	.29	[illegible]
1918	[illegible]	2	2.83	.29	3.12
1918	[illegible]	5	5.00	.29	5.29
[illegible]	15	[illegible]	5.00	.58	[illegible]
[illegible]	14	[illegible]	2.33	.58	[illegible]
[illegible]	10	[illegible]	4.17	.58	[illegible]
[illegible]	12	5	3.00	.58	[illegible]
[illegible]	[illegible]	3	3.17	.58	3.75
[illegible]	[illegible]	5	4.08	.58	[illegible]
[illegible]	[illegible]	4	3.25	.58	3.83
1919	[illegible]	[illegible]	3.17	.58	[illegible]
1919	[illegible]	[illegible]	2.67	.58	[illegible]
[illegible]	11	[illegible]	4.58	[illegible]	[illegible]

[1] Abstract of table 14, Bureau of Agricultural Engineering report (24

PART III

SECTION 4.—BUREAU OF AGRICULTURAL ENGINEERING STUDIES OF CONSUMPTIVE USE OF WATER

The consumptive use of water studies conducted by the Bureau of Agricultural Engineering in San Luis Valley, Middle Rio Grande Valley, and Mesilla Valley may be considered as having two parts:

(*1*) Analysis of climatic data, water supply and irrigation records as a basis of estimating consumptive use on large representative tracts or areas. These include studies of past records and the results of field work during 1936.

(*2*) Evapo-transpiration and evaporation measurements by means of tanks and soil moisture studies. These include both native vegetation and irrigated agricultural crops.

Unfortunately funds to start the investigation were not available until April 1936, and many of the field studies could not be gotten fully under way until the latter part of May. Thus, in addition to being of limited significance because of representing only a single year, the 1936 field studies are properly subject to criticism because they are not completely representative even to that extent. With full realization of their limitations, the results of the 1936 field studies are nevertheless believed to be of value, and accordingly are set out at the proper place in this report.

In most of the early studies of the consumptive use of water in the West, needs for irrigation have been the major motivating element. Naturally, therefore, the approach has been from the point of view of irrigated agriculture and the basic units of time and of area used have been the crop year and the crop area. These units were used in the report of the committee of the American Society of Civil Engineers in a report on Consumptive Use of Water in Irrigation (25).

However, for the Bureau's Rio Grande studies it was decided to use the 12-month year instead of the crop year as used by the society's committee, and the geographical unit of area as well as the irrigated area within each geographical unit. Moreover, the consumptive uses of water by native vegetation and by bare land and water surfaces are important factors of the Bureau's Rio Grande studies. It has therefore been necessary to add new definitions and symbols to those used by the committee. Methods of procedure heretofore used have been extended in the Bureau's studies.

Methods of Estimating Valley Consumptive Use

Three methods have been used by the Bureau of Agricultural Engineering to estimate valley consumptive use. These methods are designated as follows:

A. *The inflow-outflow method*, which is the measurement of the amount of water flowing into and out of a given area, including precipitation, and change in ground-water storage. Thus Valley consumptive use (K) is equal to the amount of water that flows into the Valley during a 12-month year (I) plus the yearly precipitation on the valley floor (P) plus the water in ground storage at the beginning of the year (G_s) minus the amount of water in ground storage at the end of the year (G_e) minus the yearly outflow (R); all amounts measured in acre-feet.

B. *The Integration method*, which is the summation of the products of consumptive use for each crop times its area, plus the consumptive use of native vegetation times its area plus water surface evaporation times water surface area plus evaporation from bare land times its area.

C. *The Hedke heat-consumption method*, which is the application of a linear relation between the consumptive use of water and the heat available for production of crops each month, and for the season (25) (26).

More than any other method, the inflow-outflow method of estimating consumptive use of water for large areas has been applied by engineers; but definitions are essential in order to segregate Valley consumptive use into its component parts, such as use by crops, native vegetation, and evaporation from bare and fallow land and from water surfaces. Methods B and C have been used primarily in Mesilla Valley.

Combinations of methods A and B have in some cases seemed fruitful and the results of such combinations are also presented.

Definitions, symbols, equations used, and essential details of procedure in estimating consumptive use are presented below.

Bureau of Agricultural Engineering Usage

1. *Time period.*—A 12-month period beginning January 1 is used as the unit of time.

2. *Precipitation used.*—*All* the precipitation during the *entire year* is considered as water consumptively used whenever precipitation is included in the computations. The product of the area (acres) within the exterior boundaries and the annual precipitation in feet is taken as the acre-feet contribution.[1]

[1] It is recognized that some of the rain coming in small showers is of but little, if any, benefit to crops. Yet such rain is "consumed" very soon after falling. Rainfall thus consumed is designated "nonbeneficial" consumptive use. Probably the major value of the precipitation, as suggested by Hedke (26), is in the substitution of the moisture thus made available for soil moisture provided by irrigation, to supply the evaporation from the area.

Evaporation loss after a rainstorm is influenced by many factors such as temperature, wind movement, soil type, kind of vegetation, interception, and periods between storms. Observations made in southern California by the Bureau of Agricultural Engineering indicate that the average evaporation loss from the top soil is about one-half acre-inch per acre after each rainstorm (4).

The Bureau does not have available sufficient experimental data relative to rates of evaporation from soils following rains in the Upper Rio Grande Basin to constitute a basis for estimating the effectiveness of the rainfall. Therefore, all the annual precipitation has been designated as a part of the consumptive use, it being recognized, however, that knowledge of the amount of stream-flow depletion (heretofore designated consumptive use by some writers) is of vital practical importance in the solution of Rio Grande water use problems.

3. *Volume of soil considered.*—Consumptive use is considered [illegible] is, [illegible] of the valley area in acres by the depth of soil which needs to be considered—usually a depth greater than the maximum depth to the water table.

4. *Water in storage.*—Water storage is considered as being in two forms: (a) Gravitational water and (b) capillary water.

5. [illegible] the change in the amount of gravitational water in the soil during the period under consideration. This is the product of the mean difference in feet in water table elevation at the beginning and end of the period, the area in acres of the valley floor and the mean specific yield of the soil.[2]

6. *Capillary water in storage.*—The volume of capillary water taken from or added to the soil is the product of the mean difference of moisture content of the unsaturated soil, dry weight basis, the mean volume weight of the soil, the depth of the soil in feet, and the area in acres of the valley floor.[3]

7. *Water inflow.*—All water flowing into or over the volume of soil under consideration during the time period selected, both surface and subsurface streams, is considered as water inflow.

8. *Outflow.*—All water flowing out of the volume of soil considered during the time period selected, both surface and subsurface, is considered as water outflow. (See also details under "Symbols and Equations.")

9. *Stream-flow depletion.*—This term has previously been defined (see p. 326). Briefly, the expression "stream-flow depletion" means the inflow less the outflow, and usually in past studies, though not always, its application has been confined to surface streams. In those cases where stream-flow depletion is considered for a valley the "outflow" may be concentrated and measured at only one place, whereas the "inflow" usually occurs in a number of streams and must be measured at several places. If it is desired to determine "stream-flow depletion" on parts of valley areas, usually several inflowing and outflowing streams must be measured.

10a. *Consumptive use.*—The Valley consumptive use includes all transpiration and evaporation losses from lands on which there is growth of vegetation of any kind, whether agricultural crops or native vegetation, plus evaporation from bare land and from water surfaces. The water consumed by native vegetation, evaporated from bare and fallow land surfaces, and from water surfaces, is designated as "non-beneficial" consumptive use.

10b. *Basic consumptive use equation in words.*—As defined by the Bureau of Agricultural Engineering, the Valley consumptive use is equal to the amount of water that flows into the valley during a [illegible]

[2] [illegible]

[3] The decrease or increase in the amount of water in capillary water storage during the plant-growing season may be a significant item in the annual consumptive use. [illegible]

11. *Symbols.*—Quantities involved in the foregoing definitions are identified by the following symbols:

Storage at beginning of year (acre-feet):

- Gravitational water above any datum surface — G_s
- Capillary water above datum surface — C_s

Inflow per year (acre-feet):

- Surface streams, sum of — I
- Sub-surface streams, sum of — F_i

Precipitation on the valley floor per year (acre-feet) — P

Storage at end of year (acre-feet):

- Gravitational water above datum — G_e
- Capillary water above datum — C_e

Outflow per year (acre-feet):

- Surface streams, sum of — R
- Sub-surface streams, sum of — F_o

Stream-flow depletion per year (acre-feet):

- Surface inflow less outflow — $I-R$

Consumptive use per year, total for tract or valley (acre-feet):

- On cropped lands — K_c
- On fallow lands — K_f
- On native vegetation lands — K_n
- Evaporation from water surfaces — E_w
- Evaporation from bare land — E_l
- By the entire project or valley, i. e. ($K_c + K_f + K_n + E_w + E_l$) — K

Land and water surface areas (acres):

- Producing crops — A_c
- Irrigated lands — [illegible]
- Fallow lands — A_f
- Native vegetation — A_n
- Water surfaces, river plus irrigation and drain ditches — A_w
- Bare land area — A_l
- Total area of valley floor ($A_c + A_f + A_n$ [illegible]) — A
- Area of each crop each year — a
- Area of each kind of native vegetation each year — n

Stream-flow depletion per year, unit amounts (acre-feet per acre):

- Flow depletion per acre irrigated — $\frac{I-R}{[illegible]}$
- Flow depletion per acre of total tract or valley area — [illegible]

[illegible]

- [illegible]
- [illegible] of total tract or valley area — [illegible] A

Consumptive use per year, unit amounts for tract or valley (acre-feet per acre):

- Use by crops per acre irrigated — K_c/A_i
- Use by native vegetation per acre — K_n/A_n
- All uses per acre irrigated — K/A_i
- All uses per acre of tract or valley — K/A
- By each agricultural crop per acre — c
- By each kind of native vegetation per acre — v

12. *Basic Rational Equations in Mathematical Form.*—In harmony with the basic equation stated in words in article 10b, it follows that:

$$(G_s+C_s)+I+F_i+P=$$
$$(G_e+C_e)+R+F_o+K_c+K_f+K_n+E_w+E_l \quad (1)$$

It is, no doubt, clear that the annual valley consumptive use on cropped land may be estimated by summarizing the products of the annual use by each crop times the number of acres of land used to produce it. The consumptive use by native vegetation in the valley may be estimated in a similar way. It follows, therefore, that:

$$K_c = \Sigma ca = c_1a_1+c_2a_2+c_3a_3, \text{ etc.} \quad (2)$$

$$K_n = \Sigma vn = v_1n_1+v_2n_2, \text{ etc.} \quad (3)$$

Equation 1 is general in character. However, under certain conditions, it must be observed that a strict application of this equation would necessitate an assumption, either implied or specifically stated.[4]

13. *Restrictions*.—(a) The quantities C_s and C_e of equation 1 are not available for studies of consumptive use in past years for either of the 3 major valleys of the Upper Rio Grande Basin. Moreover, the difference (C_s-C_e), which may be positive or negative, is relatively small and may be neglected for present purposes.

(b) There are no measurements available for the quantities F_i, but the concensus of opinion seems to be, for the Mesilla Valley at least, that the quantity is small and may be neglected. Some engineers feel that the sub-surface inflow, F_i, probably exceeds the subsurface outflow, F_o, but all seem to be of the opinion that both quantities are relatively small.

The quantity F_o was measured by C. S. Slichter in August 1904 (74) and found to be about 0.13 second-foot, which certainly is negligible.

Applying these two restrictions, (a) and (b), and remembering that $K=K_c+K_f+K_n+E_w+E_l$, it follows from equation 1 that:

$$K=(I+P)+(G_s-G_e)-R \quad (4)$$

(c) A further restriction seemingly essential to a clear review and comparison of past studies in Upper Rio Grande Basin, is to neglect the quantities P and (G_s-G_e) on the right-hand side of equation 4. The resulting quantity, that is, $(I-R)$, as mentioned hereinbefore, has frequently been designated "consumptive use." Actually the precipitation is "consumed" in part at least. Hence to designate $(I-R)$ as consumptive use may be misleading. Rather, "stream-flow depletion" alone is properly designated $(I-R)$.

Applications

In studies of past use of water, Method A (equation 4 in particular) has been applied to two major valleys in the Upper Rio Grande basin, that is: San Luis Valley, Colo.; Mesilla Valley, N. Mex. and Tex.

However, there are noteworthy differences in the amount and the reliability of available data, and therefore differences in the assumptions introduced for each valley. Consequently it is essential to indicate procedure and list assumptions for each valley separately.

Parts of San Luis Valley.—The past studies of San Luis Valley permit the application of equation 4 in whole or in part to certain tracts in the San Luis Valley, notably the Bowen-Carmel area of some 17,300 acres, studied by Tipton and Hart; the southwest area including the Conejos area or excluding it, and the Conejos area alone, investigated by Tipton; the Bureau of Agricultural Engineering area of some 375,000 acres in the southwest; and water districts nos. 20, 21, 22, 23, and 26, studied by Osgood and Black.

The past investigations in most of these parts of San Luis Valley areas include only measurements of inflow (I) and outflow (R) and therefore constitute real stream-flow depletion studies. One of the investigations includes part of (P) and another includes part of (P) and also (G_s-G_e). Details of each of the investigations on parts of San Luis Valley area are reported.

There are no available data for past years of the quantity (G_s-G_e) for San Luis Valley as a whole.

The quantity R for the San Luis Valley as a whole is available.

Application to Mesilla Valley.—The quantity (I) for Mesilla Valley includes annual river inflow at Leasburg plus the arroyo inflow. The latter is small, relatively, and must be estimated because there are few, if any, reliable measurements. The quantity (P) is the product of the calendar year precipitation in feet and the area of the valley floor in acres. Records are available for only one rainfall station in the valley; namely, State College. Therefore, considering the Mesilla Valley as a whole, it is possible to make only approximations of the volume of yearly precipitation.

For the quantity (R) only the records at one station need be considered; namely, those obtained at Courchesne (El Paso).

The quantity (G_s-G_e) is considered as a unit so that absolute evaluation of either (G_s) or (G_e) is unnecessary the difference only being needed. This is the product of the difference in the average depth of water table in January of 1 year to January of the following year, measured in feet, multiplied against the specific yield of the soil and the area of the valley floor.

For estimates of ground-water use it was assumed that the specific yield was 15 percent of the total soil volume. It should be observed that if, at the end of the year, the average depth to the water table is less than at the beginning, the quantity (G_e) is greater than (G_s) and therefore the quantity (G_s-G_e) is negative.

Evapo-Transpiration Studies in 1936

Following a survey of the Upper Rio Grande Valley in April 1936 experiment stations were established in

[4] If, for instance, an appreciable part of a valley has a water table at a great depth below the root zone, say 50 feet or more, it would be impractical to measure C_s and C_e in all the soil above the water table. In such a case it must be assumed that deep percolation losses from the soil where the water table is at a great depth do not add to the capillary soil moisture in storage in the soil below the depth to which soil moisture observations are made to determine C_s and C_e. In other words, it must be assumed, under the conditions described, that deep percolation losses from the soil root zone will contribute to ground water supplies and be measured either as increase in such storage or as subsurface outflow. (See par. 2, p. 1379 A. S. C. E. Paper 1760.) Equations 2 and 3 are general, containing no assumptions. However, accurate measurements of the quantities (c) and (v) are very difficult to make and therefore the use of equations 2 and 3 may necessitate certain assumptions.

the San Luis Valley, Middle Rio Grande Valley, and Mesilla Valley. At a conference with representatives of Texas and New Mexico it was agreed that results obtained in Mesilla Valley would be applicable to El Paso Valley and other areas in Texas above Fort Quitman.

Soil-Moisture Studies

Field plots were selected in the Middle Rio Grande Valley and the Mesilla Valley for various agricultural crops to determine consumptive use of water by means of soil-moisture studies. When possible these plots were selected in areas where the soil was fairly uniform and the depth to ground water was such that it would not influence the soil moisture fluctuations within the root zone. Suitable locations for such studies were not found in San Luis Valley, primarily because of the coarse gravel subsoil and high water table.

Soil samples were taken by means of a standard soil tube before and after each irrigation, with some sampling between irrigations, in 6-inch sections for the first foot and thereafter in 1-foot sections in the major root zone.

Standard laboratory practices were used in determining the moisture content of the soil samples (4). The samples were weighed and dried in an electric oven at 110° C. and the dry weights were determined. The water content of a sample was expressed as percentage of the oven-dry weight of the soil. From the moisture [illegible] the formula $D=\frac{MVd}{100}$ [illegible] M represents the moisture percentage, V the apparent specific gravity (or volume weight) of the soil, d the [illegible] and D the [illegible] water in acre-inches per acre.

Some of the terms used in this study are defined as follows:

[illegible] to that of an equal volume of water under standard conditions.

Real specific gravity.—The ratio of the weight of a single soil particle to the weight of a quantity of water equal in volume to the particle of soil.

Moisture equivalent.—The amount of water retained by a soil in a standardized apparatus when the moisture-content is reduced by means of a constant centrifugal force (1,000 times gravity) until brought into a state of capillary equilibrium with the applied force. It is expressed as percent of dry weight.

Field-capacity.—The amount of water retained in the soil after excess mobile water has drained away and the rate of downward movement has materially decreased following an application of water from rain or irrigation.

[illegible] on the weight of oven-dry material.

Porosity.—The property of a rock or earth of containing interstices. It is quantitatively expressed as the percentage of the aggregate volume of interstitial space to total volume.

Specific retention.—The amount of water retained against the pull of gravity by rock or earth after being saturated and allowed to completely drain to a remote body of mobile water by way of continuous capillary interstices. Specific retention is expressed ordinarily as percent by volume. To fulfill this definition in laboratory tests it is necessary to use a soil column of height considerably exceeding the height of the capillary fringe, to continue the experiment for extended periods of time, especially when working with fine-textured material, and to provide temperature control. Standardization of the limiting conditions is one of the serious problems of ground-water hydrology.

Specific yield.—The amount of water which a rock or earth will yield after being saturated and allowed to drain under the conditions specified for determining specific retention. It is expressed as percent by volume. The sum of specific retention and specific yield equals the porosity of the material drained.

Tank Experiments

The consumptive use of water by agricultural crops and by various types of moist-area native vegetation commonly found along stream beds, swamps and cienagas, was measured by means of tanks during the 1936 season at different stations throughout the Upper Rio Grande Basin. Standard Weather Bureau pans were installed at many of these stations since evaporation records are valuable in estimating evaporation losses from free-water surfaces and consumptive use of water by native vegetation growing in moist areas.

The general procedure was similar to that developed by the Bureau of Agricultural Engineering (3), (4), (48). Soil and natural vegetation were placed in the [illegible]

Mariotte apparatus was used to supply and maintain a constant water table in the soil for some of the tanks. Its value lies in the ease with which periodic measurements of water used may be made, as it is automatic in operation. However, sufficient funds were not available to equip many of the tanks with Mariotte apparatus, so the consumptive use of water was determined by measuring the amount of water applied. Either this measurement must be supplemented by determination of soil moisture at different times, or the differences in soil moisture at the beginning and end of period under consideration must be eliminated. The direct determination of the soil moisture in the tanks is scarcely practicable on account of the objectionable disturbance of the soil in the tanks when the samples are taken. The practical way of meeting the difficulty is to conduct the experiments in such manner that the difference in soil moisture at the beginning and end of the period is as nearly as possible reduced to zero. [illegible]

(1) [illegible] record, a measured amount of water was added to the

tank until the water table had stabilized at elevation close to the surface of the soil. (This elevation is called the initial observation or "zero" point in determining the consumptive use of water.) Then a measured amount of water was withdrawn until the water table in the tank had stabilized at the elevation proposed to be maintained throughout the season.

(2) Thereafter, at frequent intervals throughout the period water in measured amounts was added, the amount added each time being that calculated as sufficient to cause the water table to stabilize at the desired level.

(3) At the end of the month (or period) and at the close of the season just before harvest, a measured amount of water was added until the water table had stabilized as nearly as practicable at the initial observation or "zero" point.

San Luis Valley

Various conditions relating to the geography, soils, and climate of San Luis Valley, some of which are mentioned in preceding sections of this report, may be described together as follows:

The Valley is located in the south central part of Colorado and extends several miles into New Mexico. (See fig. 75 and p. 298). The valley floor, which in former geologic periods was the bed of a large lake, extends about 100 miles north and south, and 50 miles east and west. The farming area lies from 5,700 to 8,000 feet above sea level (p. 298).

The principal streams are: Rio Grande and Conejos River, and Alamosa, Culebra, Trinchera, La Jara, Saguache, Cottonwood, Spanish, Willow, Crestone, Cotton, Rito Alto, San Luis, Costilla, La Garita, and Carnero Creeks. The water supply for agricultural use comes primarily from these streams. The main gravity supply is the Rio Grande and Conejos River and Alamosa Creek, but considerable water is obtained from tributaries and independent creeks and, in some areas, from artesian wells. Farmers cannot rely on precipitation, although in some seasons the run-off from rains contributes materially to the flow of the streams in summer. At Manassa precipitation has averaged only 6.81 inches annually, at Del Norte only 8.19 inches; in some years it is even less. (See table 17.) During dry seasons farmers in some sections have drilled wells and pumped for irrigation from their underground supply.

The climate is characterized by dry and cool summers limited rainfall, and high spring winds. (See pp. 315 and 316). Temperature and precipitation records of the United States Weather Bureau stations in the Valley in 1936 are shown in table 45.

The soils (p. 316) are mostly sandy and in certain sections contain some alkali. The subsoil is gravelly. Large areas are waterlogged, but the gravelly subsoil makes drainage easy.

1936 Studies

In May 1936, a preliminary survey was made in San Luis Valley to locate stations and areas suitable for conducting studies on consumptive use of water.

Experiment stations were established by the Bureau of Agricultural Engineering at Parma, West ranch, Wright ranch, and San Luis Lakes. Wheat and potato tanks were installed at the West and Wright stations, native vegetation tanks at Parma station and standard Weather Bureau pans at the San Luis Lakes, Parma and West stations. Details of these experiments are described in later pages. (Pl. 11).

Rain gages were installed by the Bureau at Parma, West, Asay, and East Henry in the southwest area, and at Wright ranch and San Luis Lakes in the closed area. The precipitation records for June to November 1936 are shown in table 46.

Three large tracts were selected for the determination of stream-flow depletion and consumptive use of water in San Luis Valley by the inflow-outflow method: (1) Bureau of Agricultural Engineering Southwest area consisting of some 400,000 acres; (2) Central Southwest

TABLE 45.—*Monthly temperatures and precipitation at specified United States Weather Bureau stations in San Luis Valley, 1936*

[illegible]	Alamosa		Del Norte		Garnett		[illegible]		Saguache		Valley
	[illegible]	[illegible] inches	Mean temperature ° F.	Precipitation in [illegible]	Mean temperature ° F.	Precipitation in inches	Mean temperature [illegible]	Precipitation in [illegible]	Mean temperature [illegible]	Precipitation in inches	[illegible] precipitation in inches [illegible] stations
[illegible]	20.2	0.08	22.9	[illegible]	19.0	0.11	21.9	[illegible]	20.3	0.22	0.12
[illegible]	25.2	.15	28.6	0.33	23.8	.11	28.9	.16	[illegible]	[illegible]	.16
[illegible]	33.4	.13	[illegible]	.51	32.0	.14	35.0	.09	[illegible]	.16	.21
[illegible]	42.2	.28	[illegible]	.35	40.0	.13	43.4	.26	41.8	.33	.27
[illegible]	51.8	.16	52.6	.15	50.3	[illegible]	52.2	[illegible]	54.0	.50	.34
[illegible]	[illegible]	1.35	59.9	1.05	59.2	[illegible]	60.8	.40	62.2	.68	.83
July	[illegible]	1.00	62.1	1.15		.91	63.0	.89	65.4	2.14	1.22
[illegible]	[illegible]	[illegible]	61.2	3.78	[illegible]	3.07	61.8	[illegible]	[illegible]	2.58	3.59
[illegible]	[illegible]	1.62	55.1	1.15	51.6	1.34	53.2	[illegible]	[illegible]	.76	1.13
[illegible]	[illegible]	.69	[illegible]	.35	39.9	.71	43.6	[illegible]	41.5	.07	[illegible]
[illegible]	[illegible]	[illegible]	23.5	.20	27.3	.06	[illegible]	[illegible]	32.7	[illegible]	.06
[illegible]	23.2	[illegible]	[illegible]	.17	19.9	[illegible]	[illegible]	T	23.1	[illegible]	.05
[illegible]		9.17		9.19		7.35		10.16		[illegible]	[illegible]

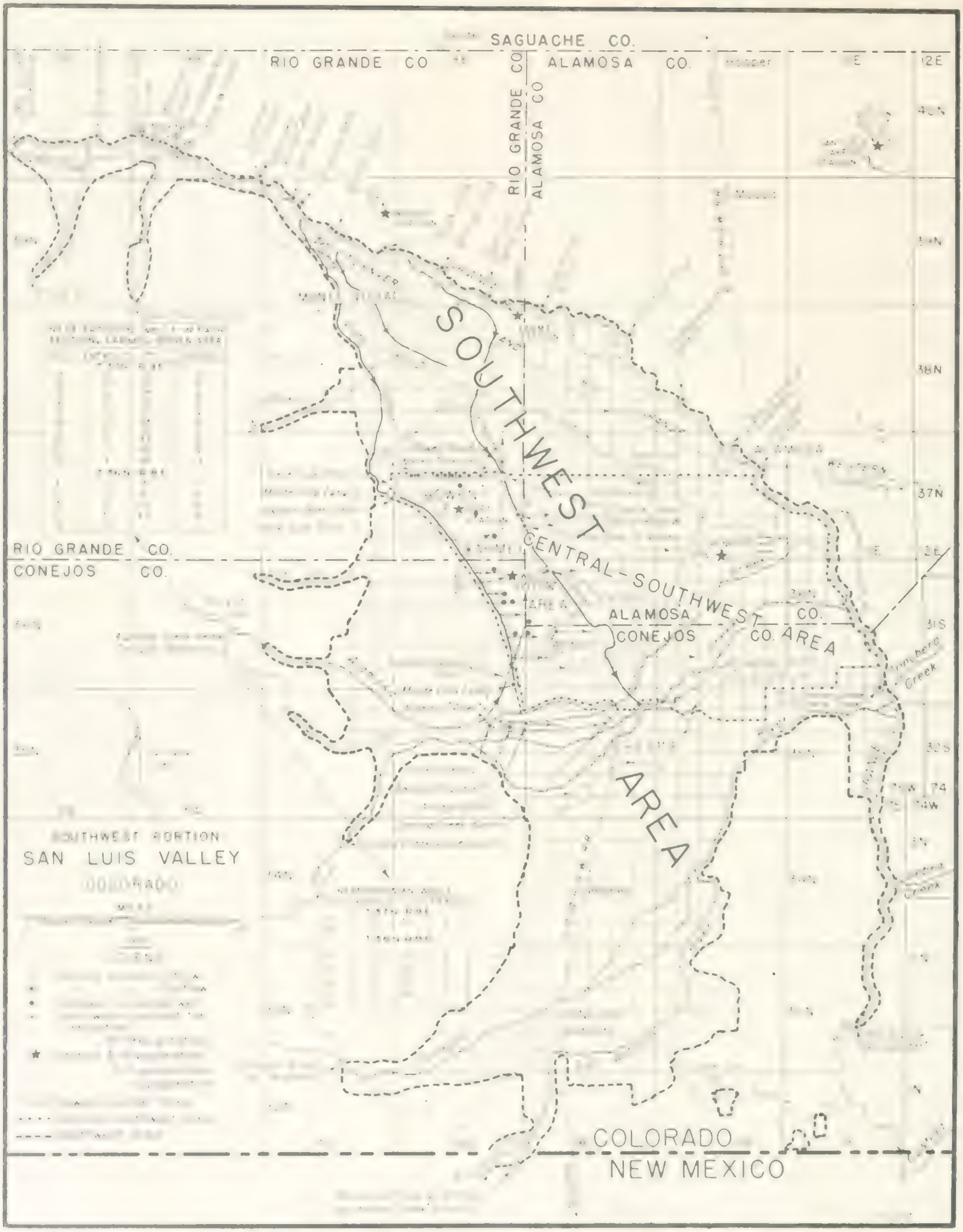

SAGUACHE CO.
RIO GRANDE CO
ALAMOSA CO.
RIO GRANDE CO
ALAMOSA CO
SOUTHWEST
CENTRAL-SOUTHWEST
AREA
RIO GRANDE CO.
CONEJOS CO.
ALAMOSA CO.
CONEJOS CO. AREA
SOUTHWEST PORTION
SAN LUIS VALLEY
COLORADO
COLORADO
NEW MEXICO
12E
38N
37N
31S
74W

TABLE 46.—*Monthly precipitation at Bureau of Agricultural Engineering stations in San Luis Valley, Colo., 1936*

Month	Precipitation in inches					
	Parma	Wright	West	Asay	East Henry	San Luis Lakes
June	1.07	0.79	0.36	0.47	0.43	1.48
July	1.16	[illegible]	[illegible]	[illegible]	1.28	2.18
August	3.06	2.62	4.13	3.77	3.51	4.26
September	1.26	.58	1.30	1.47	1.87	.64
October	.59	.14	.88	.73	1.23	[illegible]
November	.14	....	.18	.21	.20	.07

area of about 114,000 acres; and (3) Bowen-Carmel area of approximately 20,000 acres. (See fig. 78.) The latter area is practically identical with the area used by Tipton and Hart in their 1930, 1931, and 1932 studies.

Bureau of Agricultural Engineering Southwest Area

The Southwest area of the San Luis Valley was chosen by the Bureau of Agricultural Engineering for studies of stream-flow depletion and consumptive use because of the availability of practically all inflow and outflow records of importance in such investigations. One study is based on previous stream-flow measurements made by the United States Geological Survey and the State engineer of Colorado for the 11-year period 1925 to 1935. A similar study, based on measurements by the same agencies in 1936 was made by the Bureau of Agricultural Engineering.

Description.—The Southwest area, which includes all the "live" area south of the Rio Grande, is shown in figure 78. Beginning at Del Norte the boundary is the Rio Grande down to the point where it intersects the south boundary of Trinchera estate; thence it extends northwesterly to the Conejos River; thence southwesterly along the east boundary of lands irrigated by Conejos River to a point in the extreme southwestern portion of the Valley where the highest lands are irrigated from Los Pinos Creek; thence northerly to the Conejos River and up the river to the highest irrigated lands; thence northeasterly and northerly along the western boundary of lands irrigated by Conejos River and thence westerly to include all lands irrigated by La Jara Creek and Cat Creek; thence northerly and westerly to include all lands irrigated by Alamosa Creek to the point of diversion of Terrace canal from Alamosa Creek; thence northerly along Terrace canal to its intersection with Monte Vista canal; thence up Monte Vista canal to its point of diversion from Rio Grande; together with the lands irrigated by water from Rock Creek, Pinos Creek, and San Francisco Creek.

Practically all the irrigated land in water districts 21 and 22 is included in the tract, and part of the land in water district 20.

Consumptive use of water.—Determinations of consumptive use of water and stream-flow depletion for the Southwest area were made by the Bureau of Agricultural Engineering for the years 1925 to 1936, inclusive, by the inflow-outflow method. The data for 1936 are the most accurate and thus are considered separately in the following discussion.

Acreage.—The Southwest area was mapped by the Bureau of Agricultural Engineering in 1936.[5] The gross area in round numbers is 400,000 acres and the irrigated area is 224,000 acres. Table 47 shows the land classification for 1936.

The 1932 surveys of irrigated land in San Luis Valley made by John H. Bliss have been used together with the annual area estimates of Colorado water commissioners as a basis for estimating the irrigated area each year from 1925 to 1934, inclusive. Bliss found 210,000 acres irrigated within the tract in 1932. In view of the fact that the water commissioners' reports show great variation in the irrigated area of water district no. 20, and the further fact that a substantial part of district no. 20 lands are not included in the southwest area, its irrigated areas are not used as a basis for estimating the area irrigated within the tract each year. For water districts nos. 21 and 22, in 1932, the water commissioners reported an irrigated area of 144,000 acres. In order to estimate the acreage irrigated each year in the southwest area from 1925–34, the ratio of 210,000 acres to 144,000 acres was multiplied by the sum of the yearly irrigated areas in water districts nos. 21 and 22. The irrigated areas for each year, thus determined, are shown in column 5 of table 48. The 1935 crop acreage reported by commissioners for districts nos. 21 and 22 is undoubtedly too high, hence the 1936 irrigated area is used in computing the stream-flow depletion per acre for 1935.

TABLE 47.—*Classification of land in Bureau of Agricultural Engineering southwest area, San Luis Valley, Colo. and N. Mex., 1936 (Pl. 11)*

Irrigated land		Native vegetation		Miscellaneous	
Type	Acres	Type	Acres	Type	Acres
Alfalfa, clover, etc.	51,700	Grass	21,800	[illegible]	6,630
		Brush	106,000		
Grass hay	58,300	Trees and bosque.	17,600	[illegible]	[illegible]
Pasture	[illegible]			Bare land, highways, etc.	15,710
Early crops	[illegible]			Ponded water surface	[illegible]
Late crops	19,400			Water surfaces (rivers, canals, etc.).	[illegible]
Miscellaneous	6,400				
Total	224,100		[illegible]		[illegible]

NOTE.—Total area of tract 400,200 acres, or in round numbers, 400,000 acres.

Inflow.—Inflow measurements to the southwest area were made at the stations and locations shown on figure 78 and in table 49. All inflow measurements for the six major streams, as noted, were made at stations equipped with automatic recorders. Five of the sta-

[5] This area has different boundaries and is somewhat smaller than the "southwest area" discussed by the engineer in charge, Rio Grande Joint Investigation. (See fig. 78, Pl. 11, and p. 175, Part I.)

tions are classed as "good" and one as "fair", on the basis of the relative accuracy of the records they produced. Previous to 1936 inflow measurements were not made for Pinos, San Francisco, and Rock Creeks. Total diversions for irrigation as recorded by the water commissioners were taken as the inflow from these streams. The quantities thus determined are probably too small, because flood- and winter-flows were not used for irrigation; but since the total contribution from these creeks is relatively small, the estimates of inflow from this source may be considerably in error without materially affecting the accuracy of the results of the entire study. Gaging stations have been maintained for some time on San Antonio River and Alamosa, La Jara and Los Pinos Creeks, but the records for the winter months are incomplete. The data for the missing periods were estimated from the biennial reports of the State engineer of Colorado on the basis of the records for years when discharge measurements were available, nature of drainage basin, and type or characteristics of the year in relation to the mean year. The inflows from Trinchera Creek, 1925 to 1935, inclusive, were estimated by Dan Jones, special deputy State engineer of Colorado, on the basis of the average annual discharge of the creek below Smith Reservoir minus the average annual diversion for irrigation between the reservoir and the mouth of the creek. The annual contribution of Culebra Creek was considered negligible as practically all the water is utilized for either direct irrigation or storage purposes before it reaches the Rio Grande. (Pl. 11.)

Return Flow from North.—The amount of the average annual return flow to the Rio Grande below Del Norte was taken as 55,440 acre-feet. This estimate is based on the seepage investigation conducted by the State engineer's office during 1924 and the experience of Dan Jones, who is in charge of the distribution of the waters of the Rio Grande. The average annual return flow to the river from outside the southwest area or, in other words, from the north side of the river, was assumed to be one-half of the amount, or 27,720 acre-feet. The yearly return flow was then computed on the assumption that it has the same relation to the average return flow as the annual discharge at Del Norte has to 706,900 acre-feet, the mean annual discharge of the river for a 46-year period. The return flow from the north for each year from 1925 to 1936 was computed on the basis of this assumption.

Inflow from Artesian Wells.—The inflow from artesian wells was not included because prior to 1936 no records were available and in 1936 the records for only a portion of the area (central southwest) for the period May to December were available. [illegible]

Outflow.—In view of the fact that a considerable amount of the flow of the Rio Grande at Del Norte is diverted from the river to irrigate lands to the north, most of which are in the "closed" area, the diversions by 18 canals and ditches are considered as outflow which, together with the outflow of the Rio Grande at Labatos (State line station), constitutes the total annual outflow. For the irrigation canals and ditches only the seasonal outflow (as obtained from the records of the water commissioners and from the State engineer's reports) are considered; whereas, both the monthly and the annual outflow of the Rio Grande near Lobatos are included. (Pl. 11.)

The outflow through the large Rio Grande, Farmers' Union, and San Luis Valley canals includes reservoir water. This is true also of the smaller Midland canal and Kane and Callen ditch. The reservoir water is, of course, measured also at points of inflow to the area and therefore is included in the total annual inflow.

Ground-Water Storage.—No account was taken of the changes in ground-water storage in either study as no records for the area were available prior to 1936 and then for only a portion of the area during part of the year. It is believed, however, that the net effect of changes in ground-water storage throughout the year was small because most of the area is drained and the tendency would be for the drains to lower the ground water to the level of the drains during the winter when no irrigation water is being applied. (Pl. 5.)

Precipitation.—The quantity P for the Southwest area for the years 1925 to 1935 was computed from the Weather Bureau records of the Del Norte and Manassa stations and the total area of the tract as determined by the 1936 crop survey by the Bureau of Agricultural Engineering. This area in round numbers is 400,000 acres. For the 1936 study on this tract, the Weather Bureau monthly records for Del Norte, Manassa, and Alamosa for the entire year and the Bureau of Agricultural Engineering's records for the Parma, East Henry, West, and Asay stations for the period from June to November, inclusive (see tables 45 and 46), were used, together with the 1936 survey acreage of 400,000 acres in computing the contribution to the water supply by the precipitation.

Results for 1925 to 1935.—The results of the stream-flow depletion and consumptive use studies for the years 1925 to 1935, determined as explained above, are given in table 48. The amounts of the inflow to and outflow from the tract for each year are given in columns 2 and 3, and the acreages irrigated in column 5. The stream-flow depletion (inflow minus outflow) is given in column 4 and the stream-flow depletion per acre irrigated in column 6. The latter values have a range of from 2.60 acre-feet per acre in the wet year 1932 to 1.33 acre-feet per acre in the extremely dry year [illegible]. The average for the entire period is 1.92 acre-feet per acre. The last four columns in table 48 give the annual precipi-

TABLE 48.—*Use of water in Bureau of Agricultural Engineering Southwest area, San Luis Valley, Colorado, for years 1925 to 1935*[1]

Year (1)	I, acre-feet (2)	R, acre-feet (3)	$I-R$, acre-feet (4)	A_i, acres (5)	$\frac{I-R}{A_i}$, acre-feet per acre (6)	P, acre-feet (7)	$I+P-R$, acre-feet (8)	$\frac{I+P-R}{A_i}$, acre-feet per acre (9)	$\frac{I+P-R}{A}$, acre-feet per acre (10)
1925	1,174,300	[illegible]	459,100	250,000	1.84	228,000	687,100	2.75	1.72
1926	1,184,100	[illegible]	379,600	239,000	1.59	186,000	565,600	2.37	1.41
1927	1,642,200	1,107,900	534,300	237,000	2.25	259,000	793,300	3.34	1.98
1928	1,087,500	692,800	394,700	239,000	1.65	231,000	625,700	2.62	[illegible]
1929	[illegible]	1,633,500	532,100	230,000	2.31	312,000	844,100	3.67	2.11
1930	1,011,600	616,300	395,300	212,000	1.86	194,000	589,300	2.78	1.47
1931	652,600	329,400	323,200	196,000	1.65	269,000	592,200	3.02	1.48
1932	1,637,200	1,092,100	545,100	210,000	2.60	191,000	736,100	3.50	1.84
1933	947,400	562,600	384,800	191,000	2.01	297,000	681,800	3.57	1.70
1934	530,200	276,200	254,000	191,000	1.33	165,000	419,000	2.19	1.05
1935	1,291,400	841,700	449,700	[4] 224,000	2.00	330,000	779,700	3.48	[illegible]
Average	1,156,700	[illegible]	422,900	219,900	1.92	242,000	[illegible]	3.02	[illegible]

[1] As indicated by Bureau of Agricultural Engineering estimates of inflow (I), outflow (R), stream-flow depletion ($I-R$), irrigated area (A_i), total area (A), stream-flow depletion per acre irrigated $\frac{I-R}{A_i}$, precipitation (P), consumptive use as measured by inflow plus precipitation minus outflow ($I+P-R$), consumptive use per irrigated acre $\left(\frac{I+P-R}{A_i}\right)$, and consumptive use per acre for entire area $\left(\frac{I+P-R}{A}\right)$.

[2] Estimated from Bliss survey of 1932 and Colorado water commissioners' figures for districts 21 and 22 for years 1925 to 1934, inclusive.

[3] The average of the annual precipitation at Del Norte station and Manassa station multiplied by 400,000, the acreage of the Southwest area (A).

[4] Bureau survey figure for 1936 was used as water commissioners' figures for 1935 apparently are too high.

TABLE 49.—*Use of water in Bureau of Agricultural Engineering Southwest area, San Luis Valley, Colorado and New Mexico, as determined from inflow, outflow, and precipitation records, 1936*

Item	January	February	March	April	May	June	July	August	September	October	November	December	Annual
	Acre-feet												
Inflow:													
Rio Grande at Del Norte	9,320	9,970	13,880	67,330	141,200	89,150	39,550	37,570	27,100	15,130	12,390	9,710	472,300
Pinos Creek	[1] 400	[1] 400	[1] 450	5,200	5,930	2,620	1,000	1,880	972	681	[illegible]	[1] 550	20,843
San Francisco Creek	[1] 100	[1] 100	[1] 100	600	862	320	[illegible]	502	217	137	108	[1] 100	3,321
Rock Creek at Monte Vista	[1] 150	[1] 200	[1] 200	1,335	2,230	[illegible]	457	1,210	453	[illegible]	403	[illegible]	8,242
Cat Creek				[1] [illegible]	[1] 100								200
Alamosa Creek below Terrace Reservoir	2,070	1,860	1,920	13,180	24,200	13,630	6,770	6,990	4,630	1,890	1,790	1,840	80,770
La Jara Creek above Capulin	[1] 150	[1] 200	[1] 250	[1] 500	1,380	[illegible]	1,960	691	523	650	421	[1] 400	7,674
Conejos River at Mogote	2,100	2,540	3,870	47,630	87,900	34,300	8,760	13,310	9,870	9,440	7,540	4,130	231,400
Los Pinos Creek at Ortiz	[1] 1,200	[1] 1,500	1,891	36,320	32,430	8,370	2,270	2,930	1,960	3,300	2,960	[1] 2,900	98,031
San Antonio Creek at Ortiz	[illegible]	[1] 1,000	1,180	15,180	4,010	[illegible]	394	941	182	467	875	[1] 900	26,235
Trinchera Creek at mouth	[1] 100	[1] 140	[illegible]	[1] 200	171	14	10	419	619	1,180	2,000	[1] 1,000	6,343
Culebra Creek at mouth					0	0	10	96	[illegible]	0	0		106
Return flow from north [2]	1,570	1,470	1,580	1,520	1,570	[illegible]	1,570	1,570	1,530	1,570	1,520	1,580	18,580
Total	17,960	19,380	25,821	189,095	301,983	151,547	62,926	68,109	48,056	34,891	30,767	23,510	974,045
Outflow:													
Park and Green Ditch				210	310	240	120	124	120	[illegible]	0		1,132
Rio Grande Canal		615	6,530	28,190	50,620	29,460	13,640	22,470	18,000	12,780	272		182,577
[illegible] Canal				405	1,030	[illegible]	[illegible]	287	161	409	[illegible]		3,749
Rio Grande no. 2 Canal				224	248	240	248	248	272	124	0		1,604
Kane and Cohen Ditch				380	[illegible]	451	473	[illegible]	348	0	0		2,684
Farmers' Union Canal			0	6,200	15,970	16,050	7,380	34	37	39	4		45,714
[illegible] Ditch			0	126	186	180	186	186	180	[illegible]	30		1,260
McDonald Ditch			144	716	[illegible]	840	871	852	568	248	40		[illegible]
Prairie Ditch				1,480	5,920	2,500	424	240	176	100	17		10,857
Hubbard Ditch			0	[illegible]	62	60	62	26	20	0	[illegible]		284
Butler Ditch			32	[illegible]	432	420	[illegible]	236	182	124	[illegible]		1,892
Fish Ditch			0	200	284	[illegible]	217	80	26	0	0		1,017
[illegible] Ditch			0	942	1,830	[illegible]	474	219	67	51	[illegible]		4,285
San Luis Valley Canal			793	3,380	7,700	3,470	1,320	461	1,110	2,560	992		21,786
[illegible] Ditch			0	660	[illegible]	3,180	2,360	638	628	157	187		12,010
[illegible] Ditch			0	2,100	4,830	1,800	119	1,320	1,200	495	292		12,156
Independent Ditch			0	264	660	660	20	0	0	0	0		1,604
[illegible] Ditch			0	0	802	1,846	1,798	668	0	0	0		5,114
Rio Grande at Lobatos	15,380	19,800	16,000	60,420	78,700	11,040	1,060	8,970	7,740	13,890	24,680	23,270	[illegible]
Total	15,380	20,415	23,499	106,263	175,240	73,697	31,491	37,503	30,835	31,171	27,058	23,270	595,822
Stream-flow depletion ($I-R$)	2,580	−1,035	2,322	82,832	126,743	[illegible]	31,435	30,606	17,221	3,720	3,709	240	378,223
Precipitation (P)[3]	2,800	7,200	8,000	10,000	12,800	24,400	32,000	127,600	52,400	23,200	4,400	2,400	307,200
Consumptive use ($I+P-R$)	5,380	6,165	10,372	92,832	139,543	102,250	63,435	158,206	69,621	26,920	8,109	[illegible]	685,423
Stream-flow depletion per irrigated acre $\left(\frac{I-R}{A_i}\right)$[4]	0.01	−0.005	0.01	0.37	[illegible]	0.35	0.14	0.14	0.08	0.02	0.02	0	[illegible]
Consumptive use:													
Per irrigated acre $\left(\frac{I+P-R}{A_i}\right)$	0.02	0.03	0.05	0.41	0.62	[illegible]	0.28	0.71	0.31	0.12	0.04	0.01	3.06
Per acre (entire area) $\left(\frac{I+P-R}{A}\right)$[5]	0.01	0.02	0.03	0.23	0.35	0.25	0.16	0.39	0.17	0.07	0.02	0.01	1.71

[1] Estimated by comparison with streams for which monthly records were available.

[2] [illegible]

[3] Based on Del Norte, Manassa, and Alamosa precipitation records, except from June to November, inclusive, when records for Parma, West, Asay, and East Henry were included. Total area of tract used (400,000 acres).

[4] Irrigated area 224,000 acres, from 1936 crop survey.

[5] Entire area, 400,000 acres, from 1936 crop survey.

[illegible] acre-feet on the entire area (column [illegible]), the consumptive use of the entire tract (column 8), the consumptive use per irrigated acre (column 9), and the consumptive use per acre of the entire tract (column 10). The average consumptive use per acre irrigated during the 11-year period is 3.02 acre-feet per acre and the average consumptive use per acre of the entire tract is 1.66 acre-feet. The range of the latter values is from 2.11 acre-feet per acre in 1929 to 1.05 acre-feet per acre in 1934, one of the dryest years on record. During this year the total supply of water available per acre was not sufficient to produce a normal growth in the crops or the native vegetation.

Results for 1936.—The results of the 1936 use-of-water study of the Bureau of Agricultural Engineering southwest area are reported in table 49. As shown in the table the annual stream-flow depletion in acre-feet per irrigated acre is 1.69, the annual consumptive use in acre-feet per irrigated acre is 3.06, and the annual consumptive use in acre-feet per acre of entire area is 1.71. The average values for these items as determined by the study of the same area by the Bureau for the 11-year period from 1925 to 1935 (table 48), are, respectively, 1.92, 3.02, and 1.66 acre-feet per acre.

Comparison With Tipton's Estimates.—For the purpose of comparing the results of the stream-flow depletion and consumptive use studies of the Bureau of Agricultural Engineering with those made previously, the data in tables 23 and 24, considered heretofore under the heading "Tipton", were combined in table 50. In reviewing the following discussion concerning table 50, it is essential to make reference to tables 23 and 24 which, for the years 1930 to 1934, were computed by the Bureau of Agricultural Engineering following the plan used by Tipton for the years 1921 to 1929.

The combined area, as shown, is nearly 191,000 acres. As shown in part A of table 50, the 9-year average stream-flow depletion from 1921 to 1929 is 2.24 acre-feet per irrigated acre. The minimum 1.15 acre-feet in 1924 is less than one-half of the maximum of 3.10 acre-feet in 1929. The average stream-flow depletion in acre-feet is 428,000 as compared to 422,900 for the period 1925 to 1935 shown in column 4 of table 48.

For the 5 years, 1930 to 1934, the inflow to and the outflow from the Tipton southwest area have been extended on the same plan followed by Tipton for the previous years and the results are summarized in part B of table 50, which shows (column 9) that the consumption was smaller for the 5-year period 1930 to 1934 than during the earlier 9-year period. This was caused in part by two very dry years, 1931 and 1934. The average for the 5-year period was only three-fourths of the earlier 9-year average. The true irrigated area for 1930 to 1934 would probably have exceeded the constant area used in the computations (that is, 191,000 acres), because of the general trend toward increase, but for the fact that during the very dry years of 1931 and 1934 some lands normally irrigated were not irrigated because of the inadequacy of the water supply.

TABLE 50.—*Water consumption in Tipton's Southwest area, San Luis Valley, Colo., for the years 1921 to 1934* [1]

PART A [illegible]

Year	Inflow in 1,000 acre-feet			Outflow in 1,000 acre-feet			Consumption	
	[illegible]	[illegible]	Total	Conejos	Southwest minus Conejos	Total	[illegible] 1,000 acre-feet	Per acre in acre-feet
(1)	[illegible]	(3)	(4)	[illegible]	(6)	[illegible]	(8)	[illegible]
[illegible]	[illegible]	[illegible]	1,299	158	[illegible]	871	428	2.24
[illegible]	440	710	1,150	[illegible]	428	[illegible]	[illegible]	2.42
[illegible]	523	636	1,159	[illegible]	400	706	[illegible]	2.38
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	449	761	[illegible]	1.15
[illegible]	318	441	759	[illegible]	[illegible]	331	428	2.24
[illegible]	372	434	806	191	[illegible]	452	[illegible]	1.96
[illegible]	492	770	1,262	251	481	[illegible]	[illegible]	[illegible]
1928	280	408	[illegible]	115	215	330	358	1.88
[illegible]	450	[illegible]	1,018	[illegible]	219	426	[illegible]	3.10
Average	[illegible]	[illegible]	1,014	[illegible]	375	[illegible]	428	2.24

PART B [illegible]

[illegible]	315	322	637	137	231	368	269	1.41
1931	179	234	[illegible]	41	[illegible]	[illegible]	264	1.38
1932	540	570	1,110	312	268	[illegible]	530	2.78
1933	304	[illegible]	594	120	137	257	337	1.77
[illegible]	142	205	347	32	94	126	221	1.16
Average	296	324	620	128	168	[illegible]	324	[illegible]

[1] [illegible] is equal to the sum of the areas used by Tipton, 75,000 acres and 115,890 acres, or [illegible]

[2] [illegible]

[3] [illegible] computed by the Bureau of Agricultural Engineering on the basis of Colorado State engineer's water measurement records.

Precise comparisons of Tipton's 1930 estimates with those made herein for the Bureau of Agricultural Engineering Southwest area are not possible, but fairly close comparisons have been made and seem to be reliable. As just noted, the area for the Tipton estimates was considered constant; whereas, as shown in table 48, column 5, the Bureau estimates of area are different from year to year and the average exceeds the Tipton area by 28,900 acres.

The inflow and outflow measurements by Tipton did not cover exactly the same conditions as those used by the Bureau of Agricultural Engineering, the principal difference being that Tipton did not include the inflow from Pinos, San Francisco, Cat, Trinchera, and Culebra Creeks. The average annual contribution by these five streams for the period 1925 to 1935 was approximately 26,000 acre-feet.

The Rio Grande annual discharge at Del Norte plus seepage return along the river to Alamosa should equal the sum of the diversions to the south, plus diversions to the north, plus annual discharge of the Rio Grande

at Alamosa (Tipton's station for measuring inflow). In the Bureau analysis the sum of the "diversions to the north" is considered outflow, which is equivalent to designating them negative inflow. In combining Tipton's compilations (table 50) the La Jara drain is made to appear as both outflow and inflow, and therefore balances. The Conejos at its mouth is included in Lobatos outflow. Also, the Rio Grande at Alamosa plus diversions to the south in Tipton's inflow balance the Bureau's showing of inflow of Rio Grande at Del Norte plus return seepage from the north and the diversion to the north considered as outflow.

It is therefore evident that the Bureau's stream-flow depletion should exceed the Tipton stream-flow depletion. For the comparable period 1925 to 1929 inclusive, the Bureau's stream-flow depletion ($I-R$) of 460,000 acre-feet exceeds the Tipton ($I-R$) of 456,000 acre-feet for the period by an average of 4,000 acre-feet.

Central Southwest Area

Stream-flow depletion and consumptive use studies were made by the Bureau of Agricultural Engineering on the central southwest area during 1936. This is a large tract of land for which it is possible to measure the principal factors influencing the use of water. The location of the area is shown in figure 78.

Description.—The central southwest area has for its northern boundary the east-west section line which goes through the southern part of Alamosa, and for its southern boundary Alamosa Creek and the lower end of the Empire canal. The Rio Grande is the eastern boundary and the Monte Vista canal the western boundary. There are minor deviations from these boundaries as may be observed by reference to figure 78, but in general the boundaries are as described.

The western portion of the area is mostly in cultivation, but the eastern portion is largely pasture land and native meadowland cut for hay. The area was mapped by the Bureau of Agricultural Engineering in 1936, and the crop classification as determined by the survey is as shown in table 51. The total area mapped was 113,995

TABLE 51.—*Classification of land in Central Southwest area, San Luis Valley, Colo., 1936*

Irrigated land		Native vegetation		Miscellaneous	
Type	Acres	Type	Acres	Type	Acres
Alfalfa, clover, etc.	18,140	Grass	8,640	Temporarily out of cropping.	1,730
Grass hay	19,280	Brush	40,180	Towns	12
Pasture	4,830	Trees and shrubs	422	Bare land, highways, etc.	1,120
Early crops	12,830			Ponded water surface	[illegible]
Late crops	5,360			Water surfaces (rivers, canals, etc.).	[illegible]
Miscellaneous	680				
Total	61,120		49,242		3,633

NOTE.—Total area of tract 113,995 acres, or in round numbers 114,000 acres.

acre and the total area irrigated was 61,120 acres, but for the purpose of the use-of-water computations the round numbers 114,000 and 61,000 were adopted.

Stream-flow.—The principal inflow to the area comes from the Rio Grande, the Empire canal, the Monte Vista canal, Rock Creek, La Jara Creek, Alamosa Creek, and the principal outflow from the Rio Grande where it leaves the area above the mouth of Trinchera Creek. Minor flows occur at various points. The locations are shown in figure 78 and the names are listed in table 52. The principal inflow and outflow stations were all equipped with recorders, and the measurements were made by the United States Geological Survey in cooperation with the Bureau of Agricultural Engineering. Where small flows occurred, staff gages were installed which were read daily. The flows were measured by current meter or Parshall measuring flume.

Complete records were obtained for the principal stations for the period May to December, inclusive, but some of the smaller flows had to be estimated for May because observations on these stations were not started until the last of the month. Observations on some of the stations were discontinued November 30. The flows for these stations also had to be estimated. Where partial records were available the flow for the entire month was estimated on the assumption that the flow for the previous part of the month was at the same rate as that for the period for which records were obtained. When no record was available the flow was estimated on the basis of the trend of the flow of streams for which the monthly discharges were known. The December records were estimated by assuming that the rate of flow on the last day of November continued throughout December. It is believed that this assumption is not far in error because the stream flow during the winter is quite uniform.

Seepage return from the east.—There is some seepage return to the Rio Grande from the east between the Alamosa and the mouth of Trinchera Creek, but no way was devised for determining its amount. It is believed that most of the seepage return to the river comes from the west because the water table is high throughout the area along the west side of the river. This return flow is measured as outflow in the river above the mouth of Trinchera Creek.

Artesian flow.—The artesian flow in the central southwest area was measured by the Ground Water Division of the Geological Survey. In the area between the Monte Vista canal and the Empire canal (Bowen-Carmel area) the flow of every well was measured or estimated. In the remaining area the wells on every other section were measured and the total artesian flow was taken as twice the amount measured. Each well was measured once during the

TABLE 52.—*Use of water in Central-southwest area, San Luis Valley, Colo., as determined from inflow, outflow, precipitation, and ground-water-storage records, 1936*

Item	May	June	July	[illegible]	September	October	[illegible]	[illegible]	[illegible]
	[illegible]								
[illegible]:									
[illegible]	[illegible]	[illegible]	[illegible]	3,260	1,470	1,660	10,860	[illegible]	39,910
[illegible]	[illegible]	[illegible]	[illegible]	1,050	734	1,270	1,000	[1] 850	8,731
[illegible]	[illegible]	25	[illegible]	12	[illegible]	[illegible]	0	0	37
[illegible]	11,700	8,590	150	2,540	1,700	[illegible]	290	0	[illegible]
[illegible]	[1] 113	82	[illegible]	58	7	[illegible]	0	[illegible]	[illegible]
[illegible]	7,800	[illegible]	[illegible]	2,400	1,550	[illegible]	98	[illegible]	[illegible]
[illegible]	[1] 100	[illegible]	19	4	1	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[1] 160	[illegible]	5	34	75	[illegible]	[illegible]	0	[illegible]
[illegible]	[illegible]	3,080	[illegible]	660	[illegible]	[illegible]	[illegible]	[illegible]	14,522
[illegible]	[1] 280	[illegible]	[illegible]	96	[illegible]	14	2	[illegible]	[illegible]
[illegible]	[1] 770	282	[illegible]	58	[illegible]	154	[illegible]	[illegible]	[illegible]
[illegible]	2,670	1,550	337	[illegible]	1,349	2,327	2,200	[1] 1,860	13,737
[illegible]	[illegible]	[illegible]	32	15	0	[illegible]	0	0	467
[illegible]	[1] 560	[illegible]	187	406	[illegible]	609	[illegible]	[1] 550	[illegible]
[illegible]	1,690	[illegible]	[illegible]	1,690	1,630	1,690	1,630	1,690	13,340
Total	43,200	[illegible]	[illegible]	13,698	9,395	[illegible]	16,947	[illegible]	[illegible]
Outflow:									
[illegible]	[illegible]	281	[illegible]	118	121	[illegible]	251	[illegible]	[illegible]
North diversions	[illegible]	518	35	317	153	[illegible]	1	0	1,904
[illegible]	[1] 1,220	6,72	[illegible]	124	[illegible]	81	18	0	2,153
[illegible]	[illegible]	[illegible]	156	78	[illegible]	0	[illegible]	0	1,548
[illegible]	[illegible]	[illegible]	80	90	0	0	[illegible]	0	1,304
[illegible]	[illegible]	[illegible]	1,798	[illegible]	0	0	0	0	5,114
[illegible]	12,530	[illegible]	313	4,750	4,330	6,870	15,180	14,870	62,815
Total	17,610	[illegible]	[illegible]	6,151	4,747	7,204	15,750	15,170	76,842
Stream-flow depletion ($I-R$)	[illegible]	17,433	4,107	7,547	[illegible]	2,383	1,197	2,030	[illegible]
Precipitation (P) [2]	[illegible]	6,500	8,890	36,370	15,620	7,300	1,140	110	80,720
Ground-water storage (G_s-G_e)	[3] −3,590	10,600	11,800	−5,640	3,250	[illegible]	2,560	[3] 3,930	20,010
[illegible]	26,790	34,533	21,797	38,277	23,518	6,783	4,897	6,070	[illegible]
Stream-flow depletion per irrigated acre $\left(\frac{I-R}{A_i}\right)$ [4]	[illegible]	[illegible]	0.06	0.12	0.08	0.04	[illegible]	0.03	1.06
Consumptive use:									
[illegible]	[illegible]	0.57	0.41	0.63	0.38	0.11	[illegible]	[illegible]	2.72
[illegible]	0.23	0.30	0.22	0.34	0.21	[illegible]	[illegible]	[illegible]	1.45

[1] [illegible]

[2] [illegible]

[3] [illegible]

[4] Irrigated area, 61,000 acres, from 1936 crop survey.

[5] Entire area 114,000 acres, from 1936 crop survey.

year. [illegible] the wells are shut off during the winter or at least partly closed, for the purpose of conserving the artesian pressure. (Pl. 11.)

Ground-water storage.—Monthly readings were taken by the Geological Survey on the ground-water level in observation wells throughout the area during the period May to December. The readings were not all taken on the first of each month, and in order to make the readings comparable the readings for the first of each month were determined by interpolation. The observation wells in the Bowen-Carmel area were more closely spaced than in the remaining portion of the central southwest area, and in computing the change in ground-water storage the weighted averages of the changes for the two portions of the area were used. The specific yield of the soil was taken as 15 percent of the volume. The product of the change in ground-water level in feet and the area in acres multiplied by 0.15, the assumed specific yield, gave the change in ground-water storage in acre-feet.

Precipitation.—The quantity P was obtained by multiplying the average monthly precipitation in feet by 114,000 acres, the entire area of the tract. The monthly precipitation was based on the Weather Bureau records at Alamosa and Manassa, and the Bureau of Agricultural Engineering records at Parma, West, Asay, and East Henry stations. The Weather Bureau records were available for the entire period May to December, inclusive, but the Bureau of Agricultural Engineering records covered only the period June to November, inclusive.

Results.—The results of the 1936 use-of-water study of the central southwest area are set forth in table 52, which is similar to table 49, except that it includes artesian inflow and change in ground-water storage, and that it is for the 8-month period from May to December, inclusive, instead of for the year. The table shows that for the 8-month period the stream-flow depletion is 1.06 acre-feet per acre, the consumptive use is 2.72 acre-feet per acre of irrigated area, and 1.45 acre-feet per acre of entire area.

Bowen-Carmel Area

The Bowen-Carmel area was chosen for an intensive use-of-water study during 1936 for the purpose of extending the results obtained by Tipton and Hart,

engineers for the State of Colorado, when making a similar study on approximately the same area during the years 1930, 1931 and 1932. The Bowen-Carmel area is wholly within the central southwest area and its boundaries are shown in figure 78 and Pl. 11.

Description.—The Bowen-Carmel area has for its northern and western boundaries the boundaries of the central southwest area, but for its eastern boundary it has the Empire canal, and for its southern boundary the approximate line of separation between the Carmel and Morgan drainage districts. In order to simplify the water measuring problem several small tracts were included which were outside of the boundaries of the area as just given.

A larger proportion of the Bowen-Carmel area is in cultivation than either the Southwest or Central Southwest areas. The principal crops are potatoes, alfalfa, grain, field peas, and sweetclover. The distribution of the crops by area, as determined by the 1936 crop survey is given in table 53. The total area of the tract was 19,988 acres and the total area irrigated in 1936 was 13,999 acres. In making the use-of-water computations, 20,000 acres was used for the total area and 14,000 acres for the irrigated area.

The Bowen-Carmel area is drained by an extensive system of open ditches and tile drains which keep the ground-water level within safe limits over most of the area. During periods of drought, water is pumped from the drains and applied to the land. Checks are sometimes placed in the drains to raise the groundwater level in the summer.

TABLE 53.—*Classification of land in Bowen-Carmel area, San Luis Valley, Colo., 1936 (Pl. 11)*

Irrigated land		Native vegetation		Miscellaneous	
Type	Acres	Type	Acres	Type	Acres
Alfalfa, clover, etc.	[illegible]	Grass	1,200	Temporary lack of cropping.	736
Grass hay	401	Brush	3,768	Bare land, highways, etc.	190
Pasture	202	Trees [illegible]	20	Water surface (canals and drains).	75
Early crops	4,840	[illegible]			
Late crops	2,930				
Miscellaneous	[illegible]				
Total	[illegible]		4,988		1,001

NOTE.—Total area of tract 19,988 acres, or in round numbers 20,000 acres.

There are some alkali areas but alkali is not as prevalent as in other portions of the Valley.

Stream-flow measurements and estimates.—The inflow and outflow measurements on the Bowen-Carmel area were started the last week in May and were continued through November. The list of the stations at which measurements were made is given in table 54. The locations of the stations are shown in figure 78. The principal inflow to the area is the Monte Vista canal and the principal outflows are the Bowen drain, the Carmel

TABLE 54.—*Use of water in Bowen-Carmel area, San Luis Valley, Colo., as determined from inflow, outflow, precipitation and ground-water storage records, 1936*

Item	May	June	July	August	September	October	November	December	Period
	Acre-feet								
Inflow:									
West Side Ditch	[1] 110	52	19	38	7	1	0	0	[illegible]
Monte Vista Canal	7,800	4,390	946	2,400	1,550	[illegible]	98	[illegible]	17,722
[illegible] Ditch	[1] 100	36	19	1	1	0	0	0	157
[illegible] Ditch	[1] 160	56	4	34	75	[illegible]	0	[illegible]	329
Monte Vista Canal backwater	[1] 12	16	0	4	12	0	2	[illegible]	46
Scandinavian Ditch	[1] 1,190	90	5	11	[illegible]	3	[illegible]	0	1,308
Artesian wells	140	136	140	140	[illegible]	140	136	140	1,108
Total	9,512	4,776	1,133	2,628	1,790	682	236	140	20,897
Outflow:									
Bowen drain	[1] 346	281	36	118	121	253	251	[illegible]	1,706
North diversions	[1] 1,100	318	35	317	133	0	1	[illegible]	1,904
Monte Vista Canal waste	[1] 415	133	0	176	286	[illegible]	41	[illegible]	1,237
Westphall drain	[1] 40	37	22	15	13	18	18	[illegible]	178
Carmel drain	[1] 960	441	130	364	438	580	522	[illegible]	3,935
[illegible] waste	[illegible]	0	0	0	0	0	[illegible]	0	[illegible]
[illegible] King waste	0	0	0	0	0	0	0	0	0
Total	2,896	1,210	223	990	991	1,037	833	815	8,995
Stream-flow depletion $(I-R)$	6,616	3,566	910	1,638	799	−355	−597	−675	11,902
Precipitation P [3]	840	1,140	1,560	6,380	2,740	1,280	[illegible]	[illegible]	14,160
Ground-water storage G_1-G_2	−1,740	2,040	3,030	−570	540	−150	600	1,020	4,770
Consumptive use $I+P-R+G_1-G_2$	5,716	6,746	5,500	7,448	4,079	775	203	365	[illegible]
Stream-flow depletion per irrigated acre $\left(\frac{I-R}{A_i}\right)$ [4]	0.47	0.25	[illegible]	0.12	[illegible]	−0.02	−0.04	−0.05	0.85
Consumptive use:									
Per irrigated acre $\left[\frac{I+P-R+G_1-G_2}{A_i}\right]$	.41	.48	.39	.53	[illegible]	.06	.01	.03	2.20
Per acre entire area $\left[\frac{I+P-R+G_1-G_2}{A}\right]$ [5]	.28	.34	.28	.37	.20	[illegible]	.01	.02	1.54

[1] Estimated on the basis of partial monthly records.
[2] Estimated on the basis of the previous month's record.
[3] Based on Weather Bureau precipitation records at Alamosa and Manassa from May to December combined with Bureau of [illegible] records [illegible] and East Henry stations from June to November. Total area of tract used, 20,000 acres.
[4] Irrigated area, 14,000 acres, from 1936 crop survey.
[5] Entire area, 20,000 acres, from 1936 crop survey.

[illegible] and the diversions to the north. The stations on these streams were equipped with recorders, except those on the diversions to the north. Staff gages were used on these diversions and the small inflows and outflows. These gages were read daily. All measurements of flows were made with a current meter, except several of the diversions to the north which were equipped with Parshall flumes.

The Monte Vista canal is built on a flat grade where it discharges into the Alamosa Creek, and when the stream is high the water sometimes backs up the canal into the area. A record of the flow was kept and is designated as Monte Vista canal backwater in table 54. The diversions to the north are diversions from the Monte Vista canal which cross the north boundary of the area and irrigate land outside it. The Scandinavian ditch diverts water from the Alamosa Creek and crosses the Monte Vista canal into the Bowen-Carmel area. The amount brought into the area is small because the right of the Scandinavian ditch to divert water is junior to most of the appropriations on the river, and consequently it is dry most of the season.

In view of the fact that the measurements of the inflow to and outflow from the Bowen-Carmel area were not started until the latter part of May and were not continued after the last of November, it was necessary to estimate the flow in May prior to the time the observations were started and in December after the observations were discontinued. These estimates were made in the same manner as those for the central southwest area.

Artesian flow.—A complete inventory of all the artesian wells in the Bowen-Carmel area was made by the Ground Water Division of the Geological Survey. The flow of each well was measured or estimated, and if the well was either wholly or partly closed during the winter the estimate of the flow was reduced accordingly. Although the flow of the wells during the winter months was less than in summer, the use-of-water study was made on the assumption that the artesian flow was at a uniform rate throughout the year. However, the monthly flow was made to conform to the number of days in the month. (Pl. 11.)

Ground-water storage.—Ground-water level records were kept by the Ground Water Division of the Geological Survey on 30 observation wells within the Area during the period from May 15 to December 15. The observations were taken twice monthly, and as near to the first and the fifteenth of the month as possible. The readings were transferred to the desired dates by interpolation. The changes in ground-water storage were computed on a monthly basis from the mean change in level of all the wells during the period. The specific yield of the soil in the Bowen-Carmel area was assumed to be [illegible], the same as for all the other areas on which use-of-water studies were made—for the reason that sufficient specific yield determinations were not made to warrant using different values for each area. The monthly change in ground-water storage in acre-feet was obtained by multiplying the area of the tract by the change in ground-water level and by the specific yield.

Precipitation.—The contribution of the precipitation to the water supply of the Bowen-Carmel area was computed in the same manner as for the Central Southwest area, and was based on the precipitation records from the same station, but the acreage used was that of the Bowen-Carmel area.

Results.—The results of the 1936 study of the use of water on the Bowen-Carmel area for the period May to December, inclusive, are given in table 54. This table is similar to table 52 for the central southwest area. As shown in table 54, the stream-flow depletion for the period in acre-feet per irrigated acre is 0.85, the consumptive use in acre-feet per irrigated acre is 2.20, and the consumptive use in acre-feet per acre of entire area is 1.54.

Summary of Results of Large-Area Studies

The results of Bureau of Agricultural Engineering consumptive-use-of-water studies and the estimates of stream-flow depletion by different engineers are summarized briefly as follows:

Bureau of Agricultural Engineering results for 1936.—The results of the 1936 studies on the southwest, central southwest, and Bowen-Carmel areas are given in table 55.

TABLE 55.—[illegible] *Bureau of Agricultural Engineering on Southwest area, Central Southwest area, and Bowen-Carmel area*

Name of area	[illegible]	[illegible] gated acre, in [illegible]	[illegible] acre-feet
[illegible]	[illegible]	[illegible]	1.71
[illegible]	[illegible]	[illegible]	1.45
Bowen-Carmel	[illegible]	[illegible]	[illegible]

[illegible]

[1] For 8 months, May to December inclusive; includes artesian flow and change in ground-water storage.

Stream-flow depletion results.—For convenience in making comparisons, the results of stream-flow depletion per irrigated area in summary form for the period 1915 to 1936 on various areas in San Luis Valley by different engineers are presented in table 56.

The results of investigations on the Conejos Basin and the southwest area minus Conejos Basin appear in columns 2 and 3 of table 56. Column 4 is a combination of the results in columns 2 and 3, and the land represented is designated as Tipton's southwest area

since the figures are based on Tipton studies. The land represented by the Bureau of Agricultural Engineering southwest area as shown in column 5 is substantially the same as in column 4, although in column 5 the average irrigated area exceeds the area of column 4 by 29,000 acres.

The data of columns 2 and 8 are nearly comparable. Yeo and Black, New Mexico engineers, designated the Conejos area as 76,000 acres, which is 1,000 acres greater than the irrigated area found by Tipton, a Colorado engineer; but the data agree quite closely.

As noted in the title of table 56, the amounts given represent stream-flow depletion per acre irrigated $\left(\frac{I-R}{A_t}\right)$. Probably there is greater variability in the different estimates of irrigated area (A_t) than in the stream-flow depletion ($I-R$).

The averages of columns 4, 5 and 7, based on 14, 12 and 14 years respectively, are all substantially the same; that is, approximately two acre-feet per irrigated acre. This seems noteworthy in view of the fact that these averages represent time periods and areas which are not strictly identical.

TABLE 56.—*Comparison of the results of stream-flow-depletion studies on different areas in San Luis Valley, Colo. (acre-feet per acre of irrigated area).*

Year	Conejos Basin	Southwest minus Conejos	Southwest area (Tipton)	Southwest area (B. A. E.)	Bowen-Carmel area	Water district no. 20	Water district no. 22	Entire San Luis Valley
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1915						1.98		2.20
1916						[illegible]		2.82
1917						1.98		2.27
1918						1.82		2.60
1919						1.93		2.05
1920						1.89		2.48
1921	2.76	1.91	2.24			1.68	[illegible]	1.89
1922	2.40	2.44	2.42			2.43	2.48	2.55
1923	2.89	2.04	2.38			1.99	2.99	2.40
1924	1.16	1.05	1.15			1.83	2.14	
1925	2.92	1.81	2.24	1.84		2.10	2.96	
1926	2.42	1.67	1.96	1.59		1.91	2.47	
1927	3.20	2.50	2.78	2.25		2.07	3.17	
1928	2.20	1.67	1.88	1.65		2.07	2.29	
1929	3.22	2.15	3.10	2.31				
1930	2.37	.80	1.41	1.86	1.13			
1931	1.84	1.09	1.38	1.65	1.25			
1932	3.04	2.61	2.78	2.60	1.88			
1933	2.45	1.32	1.77	2.01				
1934	1.47	.96	1.16	1.33				
1935				[illegible]				
1936				1.69	[1] 1.27			
Average	[illegible]	1.73	2.05	1.90	1.38	2.01	2.66	2.36

[1] Estimated from [illegible] month record.

NOTE.—Column 2. After Tipton for years 1921 to 1929, inclusive (see table 23), and for years 1930 to 1934 extended by Bureau of Agricultural Engineering. Area 75,000 acres.
Column 3. From same source as column 2 (see table 24). Area, 115,890 acres.
Column 4. From same source as column 2 (see table 50). Area, 190,890 acres.
Column 5. Bureau of Agricultural Engineering Southwest area. Area varies from 191,000 to 250,000 acres. (See tables 48 and 49.)
Column 6. After Tipton-Hart studies (see table 25) and Bureau of Agricultural Engineering 1936 study. Area, 14,000 acres (see table 54.)
Column 7. After Yeo and Black. Area, 235,000 acres. (78)
Column 8. After Yeo and Black. Area, 76,000 acres. (78)
Column 9. Bureau of Agricultural Engineering estimates. Area, 507,000 acres. See table 28.

Wheat and Potato Tank Experiments

In the latter part of May 1936 two experiment stations were established in San Luis Valley for the purpose of determining evapo-transpiration of wheat and potatoes grown in tanks, viz, the Wright station in the closed area and the West station in the live area.

Wright station.—This station was located in adjoining wheat and potato fields on the Lyman Wright farm several miles north of Monte Vista (section 12, R. 7 E., T. 39 N.) in the subirrigated section of the closed area. The soil consisted of a 10-inch layer of sandy loam underlain with a coarse gravelly subsoil which was typical of the subirrigated section of the Valley. (Pl. 11).

Four tanks were installed at the station, two in the wheat field and two in the potato field. These tanks were 4 feet in diameter and 3 feet deep, and were made of 18-gage galvanized metal. All tanks were tested for leaks before being filled with soil. Other equipment consisted of two ground-water observation wells and a standard 8-inch Weather Bureau rain gage.

Each 6-inch layer of soil was placed in a separate pile alongside the trench as it was being excavated for the tanks. A 2-inch layer of gravel was placed in the bottom of each tank, and two wire screen cylinders, 2 inches in diameter, were placed parallel and horizontal on the gravel and connected to two vertical wells 3 feet high and 2 inches in diameter.

FIGURE 79.—Potatoes growing in tank at Wright Station, San Luis Valley.

Another layer of gravel (6 inches) was added and then the 6-inch layers of soil were replaced in their respective order until the soil was within 2 inches of the top of the tanks.

The seed in the adjacent wheat field had been drilled on April 1, 1936, and plants were transplanted from the field to the two soil tanks on June 1 in such manner as to be representative of natural field conditions.

The potatoes in the field and in the soil tanks were planted June 1. Those in the tanks were planted in rows at 10-inch intervals, with four plants to each tank. The crops in fields completely surrounded the growth in the tanks so that the exposure was normal.

The Wright station was visited at least twice a week until October; thereafter only weekly. Records were kept of depth to water table and amount of water added to or subtracted from each tank, depth to water table in the field outside the tank, and precipitation.

The water table in each tank was maintained at approximately the depths recommended by farmers using subirrigation in the adjacent farms, by adding water twice a week through the observation wells. The water tables fluctuated between 20 and 30 inches below the ground surface. For most of the period they were kept at the 22-inch level for the wheat tanks and the 18-inch level for the potato tanks.

On the first of each month the water table in the tanks was brought to a definite "zero" point near the ground surface for the purpose of eliminating differences in soil moisture in monthly consumptive-use measurements. After the water table had stabilized, water was pumped out of tank until the water table had dropped to the desired level. All water added to or withdrawn from each tank was measured. (See p. 348.) The tanks were also calibrated by adding a given amount of water at one-hour intervals and measuring the rise in water table.

The wheat was harvested September 1 and the potatoes September 15. The tanks were then used to determine evaporation from bare soil with water tables maintained at depths of 16, 18, and 19 inches.

The monthly uses of water by wheat and potatoes in tanks are shown in table 57. Evaporation from bare soil is shown in table 58.

West station.—This station was located about 8 miles southwest of Alamosa (section 1, R8E, T36N) in the Bowen-Carmel area, which is part of the so-called live area of San Luis Valley. Surface irrigation is practised in this section. The flooding method is used for wheat and the furrow method for potatoes. The 1936 climatic and soil conditions were representative of the area. The soil is gravelly but has about 10 inches of fertile top soil. Water was supplied from a nearby irrigation ditch and an artesian well.

TABLE 57.—*Monthly consumptive use of water by wheat and potatoes in tanks, Wright station, San Luis Valley, Colo., 1936*

Tank number	Crop	Consumptive use of water in calendar months (inches)				
		June	July	August	September	Total
[illegible]	Wheat [1]	3.41	6.64	4.05		14.10
[illegible]	do	3.67	6.70	3.64		14.01
[illegible]	Potatoes [2]	.70	7.93	5.66	[3] 1.44	15.73
[illegible]	do	1.74	6.43	[illegible]	[illegible]	[illegible]

[1] Crop harvested Sept. 1.
[2] Crop harvested Sept. 15.
[3] Sept. 1 to Sept. 15.

TABLE 58.—*Evaporation from bare soil in tanks at Wright station, San Luis Valley, Colo., 1936*

Period	Evaporation from bare soil, in inches		
	Tank no. 1 (depth to water 18 inches)	Tank no. 2 (depth to water 16 inches)	Tank no. 4 (depth to water 19 inches)
Sept. 15 to Oct. 1	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	.55
[illegible]	3.95	[illegible]	1.39
[illegible]	4.39	4.52	1.53

The station was equipped with two double-type tanks with an annular space of 1¼ inches between the inner and outer shells. The inner tank, which held the soil, was approximately 23$\frac{1}{16}$ inches in diameter and 6 feet deep, with a removable bottom. The outer tank was a reservoir for water which passed into the soil through the inner shell perforations (3) (4). A standard Weather Bureau evaporation pan, an 8-inch rain gage, an anemometer and two ground-water observation wells were also installed at the station.

The soil tanks were filled by the same methods used at the Wright station. One tank was placed in a wheat field and the other in a potato field, and they were completely surrounded by the crops. The wheat, which had been planted in the field April 3, 1936, was transplanted in one tank on June 1. The plants were 8 inches high and the shock resulting from transplanting retarded their growth so that throughout the season they never were as large as the plants in the adjoining field. The other tank was planted to potatoes, with two plants to the tank, on June 1, 1936.

The station was visited at least twice a week and observations were made on precipitation, wind movement, evaporation, depths to ground-water in the tanks and in the fields. Sufficient water was added to the tanks to maintain their water levels at approximately the same elevations as the water table in the adjoining fields. These varied from 24 to 53 inches below surface in the potato tank and 20 to 54 inches in the wheat tank.

On the first of each month the water table in the tanks was brought to a definite zero point near the surface (p. 348) for the purpose of determining the monthly

consumptive use of water. All water added to or withdrawn from each tank was measured. Both tanks were calibrated with water table at various depths.

The wheat was harvested on August 10 and the potatoes on October 1, and the crops were weighed. The tanks were then used until October 12 to determine evaporation from bare soil with the water table depths maintained at 18 inches in one tank and 30 inches in the other.

The monthly use of water for wheat and potato tanks is shown in table 59 and evaporation from bare soil in table 60. The weekly and monthly evaporation from water surface, wind movement and precipitation are given in table 61.

TABLE 59.—*Monthly consumptive use of water by wheat and potato tanks, west station, San Luis Valley, Colo., 1936*

Tank number	Crop	Consumptive use of water in acre-inches per acre (inches)				
		June	July	August	September	Total
1	Wheat [1]	3.38	6.19	[2] 0.77		10.34
2	Potatoes	.82	5.44	9.83	3.80	19.89

[1] Crop harvested Aug. 10.
[2] Aug. 1 to Aug. 10.
[3] Crop harvested Oct. 1.

TABLE 60.—*Evaporation from bare soil in tanks at west station, San Luis Valley, Colo., 1936*

Period	Evaporation from bare soil, in inches	
	Tank no. 1 (depth to water level 18 inches)	Tank no. 2 (depth to water level 30 inches)
Aug. 10 to Sept. 1	[illegible]	
Sept. 1 to Oct. 1	[illegible]	
Oct. 1 to Oct. 12	.91	1.28
Aug. 10 to Oct. 12	6.82	

Tank Experiments—Native Vegetation and Evaporation

In order to obtain some measure of the quantity of water used by native plants growing in moist areas of San Luis Valley during 1936, an evapo-transpiration station was established at Parma and an evaporation station at San Luis Lakes. (Pl. 11.)

Parma station.—This station was located 6 miles east of Monte Vista (section 1, R8E, T38N) in a swamp of tules and native grasses just south of Rio Grande. A small plot in which to place the equipment was fenced with woven wire to protect the station from animals. The soil was heavy and somewhat impervious to the depth of 6 feet, and was mixed with vegetative matter. The Centennial canal, about 150 feet south of the station, appeared to supply water to the swamp by seepage. A good supply of water for the station

TABLE 61.—*Weekly and monthly evaporation and meteorological data at West station, San Luis Valley, Colo., season of 1936*

Date	Evaporation in inches	Wind movement		Precipitation in inches
		Miles	Miles per hour	
Week ending—				
June 22	2.66			[illegible]
[illegible]	2.31			.23
Month, June	[illegible]			[1] .35
Week ending—				
[illegible]	2.49	[illegible]	2.76	
[illegible]	2.21	[illegible]	3.68	.11
July 20	2.36	393.3	2.34	[illegible]
[illegible]	2.13	300.7	1.78	[illegible]
Month, July	[illegible]	1,882.5	[illegible]	[illegible]
Week ending—				
Aug. 3	[illegible]	321.9	1.94	[illegible]
Aug. 10	[illegible]	298.2	1.77	.58
Aug. 17	1.89	[illegible]	1.93	.16
Aug. 24	1.44	277.6	[illegible]	.89
Aug. 31	1.56	322.7	1.92	.87
Month, August	6.67	1,353.1	1.77	4.13
Week ending—				
Sept. 7	1.82	[illegible]	2.67	.02
Sept. 14	1.46	426.6	2.54	[illegible]
Sept. 21	1.23	413.4	2.46	[illegible]
Sept. 28	.55	645.4	3.84	[illegible]
Month, September	5.35	[2] 1,008.4 [3] 443.0	[2] 2.42 [3] [illegible]	[illegible]
Week ending—				
Oct. 5	.91	([4])	([4])	T
Oct. 12	.88			.42
Month, October	[1] 1.51			[1] .42

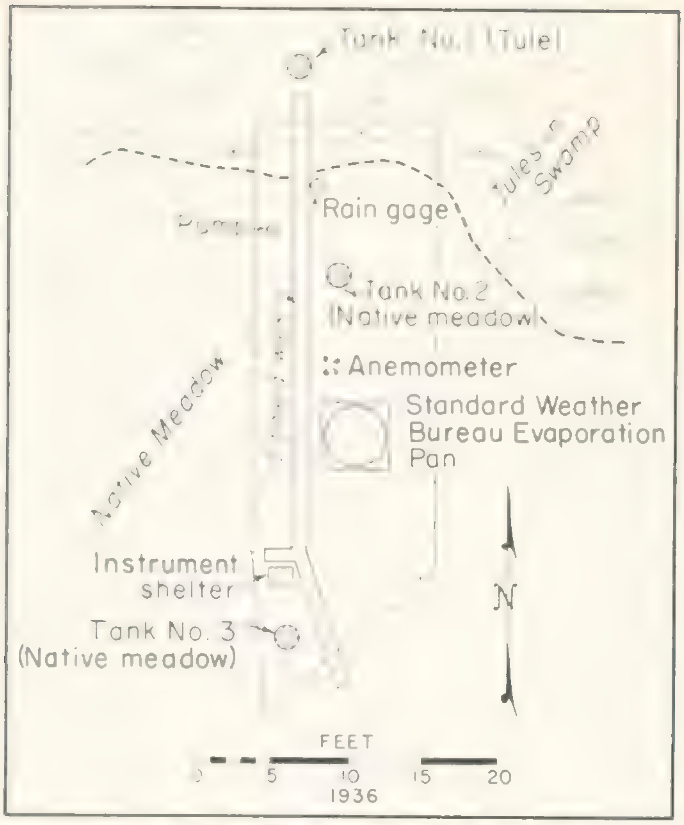
[1] For 11 days.
[2] Sept. 1 to 18.
[3] Sept. 24 to Oct. 1.
[4] Instrument cup broken.

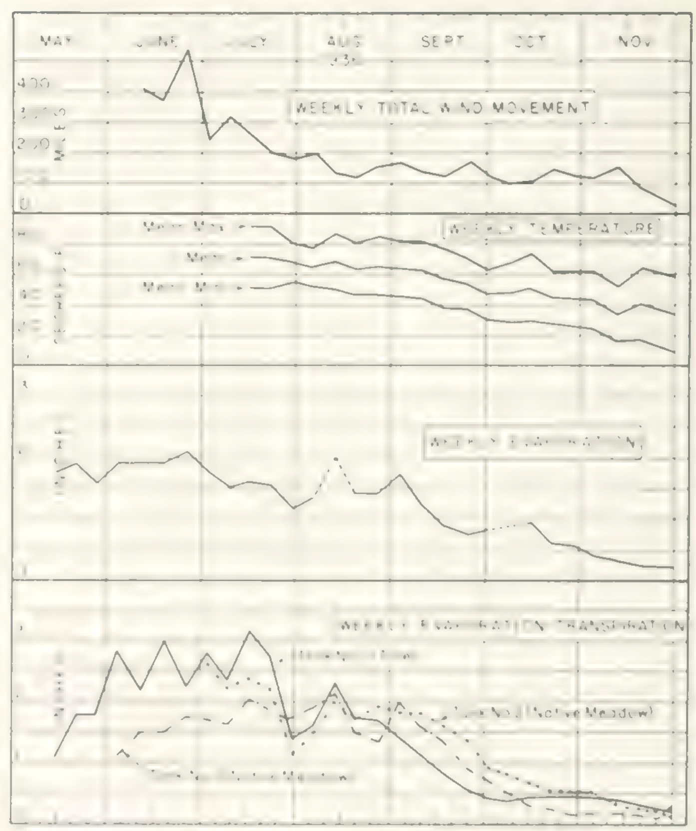
was obtained from the canal and from a well driven on the site.

The general arrangement of the station is shown in figure 80. To simulate swamp conditions the tanks were entirely surrounded by similar growth. All the tanks were made of galvanized iron and were 2 feet in diameter and 3 feet deep. Other equipment consisted of a standard Weather Bureau evaporation pan, a standard 8-inch rain gage, a thermograph, and an anemometer.

Tank no. 1 contained transplanted tules (*Scirpus americanus* and *Typha latifolia*) which developed a growth comparable in vigor with the natural tule growth in the swamp surrounding the tule tank. Several times a week a measured amount of water was added to the tank until the soil surface was covered to a depth of approximately 2 inches.

Sections of native meadow (*Agrostis idahoensis* and *Calamovilfa longifolia*) sod 24 inches in diameter and 12 inches deep were transplanted into tanks nos. 2 and 3. The water table in tank no. 2 was kept at or above the ground surface by adding measured amounts of water several times a week. Tank no. 3 was equipped with a Mariotte supply bottle to maintain the ground water at 8 inches below the surface, but this depth was not always maintained because of rains which raised the water table.





Water-use records in the tule and the two native meadow tanks were not begun simultaneously, hence comparisons of the total use of water by the different tanks prior to July may not be made. However, records from July to November, inclusive, are available for each of the three tanks. For this period the quantity of water used by tule growth in tank no. 1 was 27.32 inches of depth, with a monthly maximum of 11.60 inches in July and a minimum of 1.30 inches in November, when plant growth had ceased. Comparison of the October and November consumptive use with loss from the Weather Bureau pan for the same period indicates that all the water lost from the tule tank during this period was chargeable to evaporation rather than to use of water by plant growth. This is true also for each of the meadow tanks, as in each case the consumptive use by vegetation is less than the depth of water evaporated in the Weather Bureau pan. Thus the indications are that in San Luis Valley the growing season for native vegetation ends early in September and that transpiration by plants is not a factor in consumptive use beyond that time.

Comparison of tule tank no. 1 and native meadow tank no. 2 shows that each growth used nearly the same quantity of water during the July-November period. Tank no. 3, however, in which the water table was approximately 8 inches below the surface, con-

sumed about four inches less than the tank with saturated soil.

A measure of consumptive use is available through comparison with evaporation from a free water surface. Thus, evaporation from the Weather Bureau pan at the Parma station for the July-November period amounted to 22.54 inches or if reduced to reservoir values through use of the accepted coefficient of 0.70, to 15.78 inches. Application of this value indicates that consumptive use by the tules was 173 percent of the evaporation; use by native meadow tank no. 2 was 178 percent; and meadow grass with a water table 8 inches below the surface was 152 percent.

Data obtained at the Parma station during 1936 are shown in tabulated form as follows: Table 62, Weekly consumptive use of water, evaporation and meteorological data, and table 63, Summary of monthly consumptive use of water, evaporation and meteorological data. The weekly variations are shown in figure 82.

San Luis Lakes evaporation station.—This station was located on a neck of land between two of the San Luis lakes in section 26, R. 11 E, T. 40 N., on the same site that the State of Colorado used in 1930, 1931, and 1932. An evaporation pan of the Weather Bureau type was fenced with woven wire for protection from rabbits and other animals. The site was free from windbreaks or other obstructions. The surrounding vegetation was rabbitbrush, saltgrass, and chico.

The equipment consisted of one standard Weather Bureau pan, one 8-inch rain gage, and one anemometer

TABLE 62.—*Weekly consumptive use of water, evaporation and meteorological data of Parma station, San Luis Valley, Colo., season of 1936*

Week ending—[1]	Consumptive use of water, in inches			Average depth to water table in inches, tank no. 3	Evaporation in inches (standard Weather Bureau pan)	Meteorogical data					
	Tank no. 1—Tule in water	Tank no. 2—Native meadow	Tank no. 3—Native meadow			Temperature in degrees Fahrenheit [2]			Wind movement in total miles	Average wind movement, miles per hour	Precipitation in inches
						Mean maximum	Mean minimum	Mean			
May 18	1.02				1.70						
May 25	[illegible]				1.89						
June 1	1.76				1.47	71	[illegible]	[illegible]			
June 8	2.78		1.19	7.00	1.93	80	41	60			
June 15	2.14		1.51	9.00	1.93	[illegible]	45	[illegible]	402	2.39	0.20
June 22	2.87		[illegible]	10.25	1.93	82	46	64	374	2.23	.00
June 29	2.17		1.75	13.75	2.06	82	42	62	541	3.22	.75
July 6	2.75	[illegible]	1.68	8.50	1.66	78	43	[illegible]	[illegible]	1.44	.12
July 13	2.23	2.18	[illegible]	5.75	1.47	84	47	64	318	1.89	.27
July 20	3.09	2.34	2.04	10.75	1.59	89	51	70	[illegible]	1.46	.00
July 27	2.73	2.21	1.86	9.25	1.47	88	[illegible]	68	198	1.17	.28
Aug. 3	1.30	1.23	1.53	7.25	[illegible]	79	[illegible]	[illegible]	187	1.11	.47
Aug. 10	1.56	1.52	1.82	[illegible]	1.30	77	51	[illegible]	196	1.17	1.29
Aug. 17	2.31	2.06	2.14	8.00	[illegible]	87	48	68	122	.73	.49
Aug. 24	[illegible]	1.63	1.45	[illegible]	[3] 1.40	80	46	[illegible]	116	.69	.70
Aug. 31	1.63	1.88	1.28	11.25	1.39	82	47	64	154	.92	.00
Sept. 7	1.34	1.79	1.94	8.25	1.70	80	45	62	157	.93	.55
Sept. 14	1.10	1.71	[illegible]	7.25	1.15	80	43	62	131	[illegible]	.06
Sept. 21	.78	1.59	1.29	8.25	.91	77	37	57	120	.71	[illegible]
Sept. 28	.62	1.26	.83	7.25	.71	71	36	54	160	.95	1.15
Oct. 5	.49	[illegible]	[illegible]	.75	.77	61	28	45	116	[illegible]	.02
Oct. 12	.39	.79	.48	3.25	[3] .85	66	27	46	94	.56	.15
Oct. 19	.38	.61	.32	5.50	[3] .86	72	29	[illegible]	105	.62	.09
Oct. 26	.42	.45	.21	[illegible]	.58	[illegible]	27	42	142	.85	.20
Nov. 2	.43	.49	.15	[illegible]	.54	[illegible]	23	[illegible]	117	[illegible]	.15
Nov. 9	.41	.39	.26	7.50	.12	[illegible]	15	[illegible]	152	.90	.10
Nov. 16	...	.25	.23	9.50	.38	[illegible]	19	[illegible]	96	.57	.00
Nov. 23	.27	.24	.37	7.90	.33	60	17	[illegible]	56	.33	.00
Nov. 30	[illegible]	.18		11.00	[illegible]	[illegible]	10	[illegible]	[illegible]	.14	[illegible]

[1] Data for weekly periods have been corrected if time interval varied more than 1 hour.
[2] Records from May 25 to June 13 were taken at Alamosa Weather Bureau station.
[3] Estimated.

TABLE 63.—*Summary of monthly consumptive use of water, evaporation and meteorological data of Parma staion, San Luis Valley, Colo., season of 1936*

Month	Consumptive use of water in inches			Average depth to water table in inches tank no. 3	Evaporation in inches (standard Weather Bureau pan)	Meteorological data					
	Tank no. 1—Tule in water	Tank no. 2—Native meadow	Tank no. 3—Native meadow			Temperature in degrees Fahrenheit [1]			Wind movement in total miles	Average wind movement, miles per hour	Precipitation in inches
						Mean maximum	Mean minimum	Mean			
May [2]	4.02				4.15						--
June	11.45		6.51	10.00	8.26	80	42	61	[illegible]	1.79	1.07
July	11.60	9.55	8.27	[illegible]	6.52	89	50	70	1,029	1.38	.99
August	8.31	8.04	7.79	7.50	6.61	81	[illegible]	65	[illegible]	.83	3.06
September	4.10	7.79	5.80	7.75	4.70	77	[illegible]	[illegible]	616	.85	1.28
October	2.01	2.74	1.18	3.80	3.22	[illegible]	[illegible]	[illegible]	[illegible]	.65	.59
November	[illegible]	1.15	.95	8.90	1.49	[illegible]	[illegible]	36	352	.49	.14

[1] Records from May 25 to June 13 were taken at Alamosa Weather Bureau station.
[2] May 15 to 31.

with cups 20 inches above the ground level. Evaporation records were started on May 18, [illegible].

Table 64 gives monthly evaporation from a standard Weather Bureau pan, and wind movement and precipitation from May to November 1936, at San Luis Lakes station.

TABLE 64.—[illegible] *tion at San Luis Lakes station, San Luis Valley, Colo., season* [illegible]

[illegible]	[illegible]	[illegible]	Precipitation in inches
May [1]	[illegible]		
June	10.84	2,076	1.48
July	9.33	2,464	2.18
[illegible]	7.76	2,045	4.26
[illegible]	5.60	3,199	.64
[illegible]	[illegible]	3,159	.66
[illegible]	[illegible]	[illegible]	[illegible]

[1] May 18 to June 1.

Middle Rio Grande Valley

The area here considered as Middle Rio Grande Valley extends from Sandoval County, through Bernalillo and Valencia Counties to San Marcial in Socorro County, a total distance of about 150 miles. The average width is about 2 miles. The valley floor is divided into a number of units each of which may be considered a subarea of the valley proper.

Most of the land irrigated is supplied water by gravity from the Rio Grande through the system of the Middle Rio Grande Conservancy District. The district is comprised of four divisions, the Cochiti, the Albuquerque, the Belen, and the Socorro, named in order downstream. Each has its own diversion dam, main canal or canals, and distribution system. El Vado Dam and Reservoir may be considered as a fifth division. The dam is built across the Chama River in northern New Mexico about 17 miles west of Tierra Amarilla. The storage capacity of El Vado Reservoir is about 200,000 acre-feet. (See pp. 309 to 310.)

The climate of the Middle Rio Grande Valley is arid, the average annual precipitation varying from about 8 inches at Albuquerque to about 10 inches at Socorro, nearly two-thirds of which occurs during the growing season. (See tables 18 and 19.) Snowfall is light and disappears rapidly. Mean temperature and precipitation records for 1936 at Albuquerque, Los Lunas, and Socorro are shown in table 65.

The soils of the Valley consist principally of alluvial deposits and in most places are underlain by sand or gravel. Because of the water-borne method of deposit the valley soils are quite irregular. In places the subsoil contains muck, indicating former swamp areas. (See table 20.)

A preliminary survey of the Valley was made in April 1936 for the purpose of locating places with favorable conditions for conducting consumptive-use-of-water studies. Sites were selected for tank experiments and soil-moisture studies. Experiment stations were established for agricultural crops at Los Poblanos ranch 5 miles north of Albuquerque and at Phillips farm 5 miles south of Albuquerque, and for native vegetation at Isleta. Evaporation stations were installed at El Vado Dam, Isleta and Socorro. Routine observations were conducted cooperatively with the Weather Bureau and the Middle Rio Grande Conservancy District at El Vado, Middle Rio Grande Conservancy District at Isleta and the Geological Survey at Socorro. In conference with representatives of New Mexico and Texas an area on the east side of the Rio Grande between Isleta and Belen was selected for an intensive study of stream-flow depletion and the consumptive use of water in cooperation with the Geological Survey. A soil-moisture laboratory was established in the civil engineering laboratory of the University of New Mexico at Albuquerque.

TABLE 65.—*Mean temperature and precipitation records at Albuquerque, Los Lunas, and Socorro, 1936* [1]

Month	Albuquerque				[illegible]				[illegible]			
	[illegible]			[illegible]	[illegible] degrees Fahrenheit			Precipitation in inches	[illegible]			Precipitation in inches
	[illegible]	Mean minimum	Mean		[illegible]	[illegible]	[illegible]		[illegible]	Mean minimum	[illegible]	
January	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17.1	31.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	54.3	[illegible]	[illegible]	[illegible]	[illegible]	23.8	39.4	[illegible]	[illegible]	[illegible]	[illegible]	.27
March	[illegible]	30.3	47.1	11	62.4	[illegible]	[illegible]	.00	[illegible]	[illegible]	51.8	[illegible]
April	[illegible]	38.4	55.4	[illegible]	73.2	36.5	54.8	[illegible]	79.3	41.3	60.3	.03
May	[illegible]	[illegible]	65.0	.27	80.8	45.8	63.3	.37	87.6	49.6	[illegible]	.14
[illegible]	[illegible]	[illegible]	[illegible]	.43	90.6	53.1	71.8	.17	98.2	56.5	77.4	.85
July	[illegible]	62.3	77.0	.67	[illegible]	[illegible]	76.3	[illegible]	96.6	61.4	[illegible]	1.73
[illegible]	91.3	61.4	76.4	.62	90.4	58.8	[illegible]	[illegible]	95.9	[illegible]	78.0	.29
[illegible]	[illegible]	53.2	66.2	[illegible]	78.3	51.6	[illegible]	1.82	84.9	[illegible]	69.3	2.44
October	[illegible]	54.1	55.2	[illegible]	69.0	37.8	53.4	.00	75.0	39.6	57.3	.13
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	59.1	22.1	40.6	.00	62.3	27.1	44.7	[illegible]
December	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17.2	[illegible]	T	[illegible]	[illegible]	38.8	.20
Annual	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41.3	59.0	7.10

[1] [illegible]

Isleta-Belen Area

The Isleta-Belen Area is in the north end of the Belen division of Middle Rio Grande Conservancy District and includes all the land under the canal system east of the Rio Grande between the Isleta diversion dam and the highway bridge crossing the river east of Belen. It is approximately 18 miles long and has maximum width of about 3 miles. Figure 83 shows the location of the area.

Water is diverted for irrigating this area through the Chical lateral (12.74 miles long), the Chical Acequia (3.16 miles long), the Cacique Acequia (3.06 miles long), and the Peralta main canal (16.54 miles long). The tract has a drainage system consisting of several interior drains and the upper Peralta riverside drain and the lower Peralta riverside drain. The latter two parallel the Rio Grande and extend along the entire west side of the area. Automatic water stage recorders and staff gages were installed and daily discharge records compiled by the surface water division of the Geological Survey for all the main canals and drains in the area. The Ground Water Division of the Survey installed about 135 observation wells in the area and kept monthly records of ground-water fluctuations.

Acreage.—The Bureau of Agricultural Engineering 1936 survey shows that there is 21,074 acres in the Isleta-Belen area of which 9,147 acres were irrigated. About 1,200 acres is native vegetation growing along the river and thus has access to an unlimited supply of water. Table 67 shows the detailed land classification.

If the acreage between the gages on the interior drains and wasteways and the Rio Grande is excluded, the Isleta-Belen area is reduced to approximately 17,500 acres.

Inflow.—Surface water entering the area (I) through the Chical lateral, Chical Acequia, Cacique Acequia and the Peralta main canal was measured at Isleta diversion and is considered inflow. There may have been a small amount of arroyo inflow between Isleta and Belen after summer rainstorms; if so, it was negligible.

Outflow.—The "outflow" from the area was measured from Otero drain, San Fernandez drain, Tome drain and Public wasteway, which flow into the upper and lower Peralta Riverside drains, and from the lower Peralta main canal and La Constancia Acequia wasteway, which empty directly into the Rio Grande. An analysis of available data indicates that a considerable portion of the water flowing in the upper and lower Peralta Riverside drains is seepage from the river; thus the discharge measurements of these drains cannot be used as outflow (R) from the area unless a correction is applied.

Precipitation.—The number of acre-feet of precipitation (P) contributed to the area is based on the monthly record at Albuquerque for April and May and the Isleta station record for June to December 1936, inclusive.

Ground-water storage.—The amount of change in ground-water storage ($G_s - G_e$) is estimated from measurements of ground-water fluctuations in some 135 observation wells in the area made by the Geological Survey. In December 1936 the average depth to water was about 0.5 foot lower than in April 1936. An assumed specific yield of 15 percent was used. The change in ground-water storage was small, averaging only 0.08 acre-foot per acre for the area.

Consumptive use of water.—The use of water in the Isleta-Belen area was estimated by both the inflow-outflow and the integration methods.

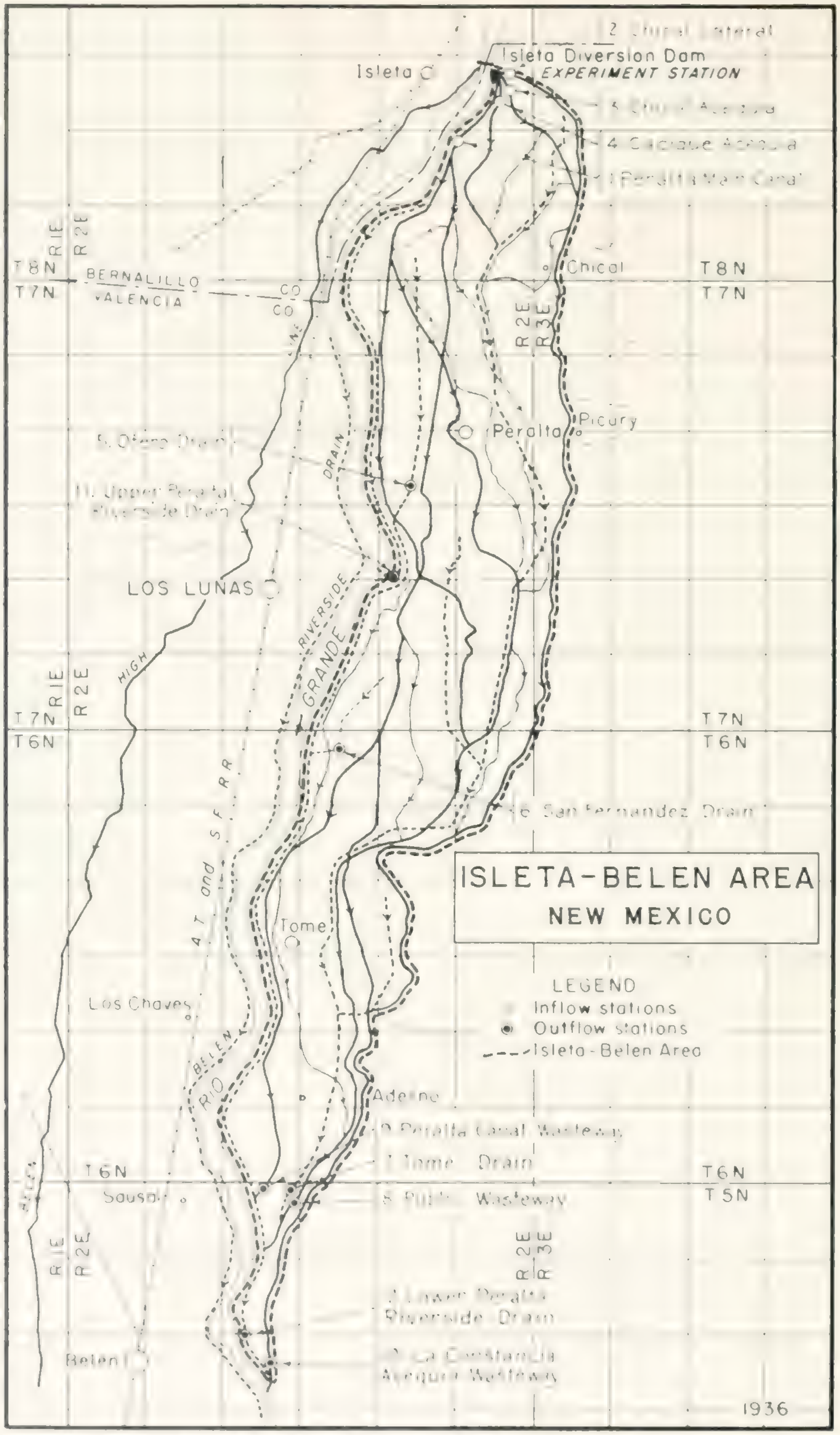
Inflow-Outflow Method.—Several analyses were made using all the canals entering the area at Isleta as "inflow" and all the canals, drains and wasteways flowing out of the area as "outflow", but no satisfactory solution was found because of the large amount of river water intercepted by drains, especially those along the river.

The most feasible method of determining the consumptive use of water in this area, with the data available, is to disregard the acreage below the gaging stations of the Otero, San Fernandez and Tome drains and the Peralta canal and La Constancia Acequia wasteway, and consider a smaller area of some 17,500 acres above these gaging stations, thus eliminating the necessity of including the uncertain outflow of the upper and lower Peralta riverside drains. Under this plan only the interior drains and wasteways are considered as outflow. However, a large portion of the section excluded supports a growth of water-loving vegetation which, if included, would probably increase the use of water in the entire area. Stream-flow depletion and consumptive use of water as determined by the above method for the period April 1936 to December 1936 are shown in table 66. The consumptive use was 4.46 acre-feet per acre of irrigated land and 2.28 acre-feet per acre for the 17,500 acres for the 9-month period. It is estimated that the annual or Valley consumptive use would be 2.7 acre-feet per acre, on the assumption that the use of water for January and February would be 0.1 acre-foot per acre per month and for March, 0.2 acre-foot.

The gross diversion or inflow to the area at Isleta, for the period, was 89,386 acre-feet or 9.8 acre-feet per acre of irrigated land and 4.3 acre-feet per acre for gross acreage of 21,000.

Integration Method.[6]—The areas of different types of land in the Isleta-Belen area have been grouped and are

The sum of the [illegible] fication by the unit consumptive use for each gives the consumptive use of the area. The process is designated the integration method.


Isleta Diversion Dam
EXPERIMENT STATION
Isleta
Chical
T8N
T7N
R1E
R2E
R3E
BERNALILLO CO
VALENCIA CO
Peralta
Picury
LOS LUNAS
HIGH LINE
RIVERSIDE DRAIN
RIO GRANDE
A.T. and S.F. R.R.
T6N
T5N
ISLETA-BELEN AREA
NEW MEXICO
LEGEND
Inflow stations
Outflow stations
Isleta-Belen Area
Tome
Los Chaves
Adelino
Sausal
Belen
1936

[illegible] N. Mex.

TABLE 66.—[illegible] *Middle Rio Grande Valley, N. Mex., [illegible] records, April to December [illegible]*—Continued

Item	April	May	June	July	August	September	October	November	December	Total	
	Acre-feet										
Inflow:											
1. [illegible]	[illegible]	10,910	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6,870	0		
2. [illegible]	2,640	2,880	1,810	[illegible]	1,990	1,510	587	1,270	[illegible]		
3. [illegible]	[illegible]	[illegible]	356	[illegible]	370	221	[illegible]	147	[illegible]		
4. [illegible]	388	614	724	419	593	[illegible]	[illegible]	183	[illegible]		
Total	[illegible]	14,912	12,330	10,094	12,013	11,241	7,760	[illegible]	[illegible]	89,386	
Outflow:											
[illegible]	119	207	222	215	190	209	211	[illegible]	277		
[illegible]	154	187	157	143	111	132	[illegible]	[illegible]	132		
[illegible]	1,720	[illegible]	2,200	2,030	2,150	2,100	1,610	1,720	1,680		
[illegible]	[1] 1,820	[illegible]	1,540	1,460	2,090	2,970	1,740	1,230	[illegible]		
[illegible]	[illegible]	[illegible]	2,280	1,370	1,390	3,470	4,460	1,570	21		
[illegible]	[illegible]	[1] 577	426	164	176	377	191	119	0		
Total	6,600	10,571	6,825	5,382	6,107	9,258	8,336	4,985	2,147	60,211	
Inflow minus outflow	5,966	[illegible]	5,505	4,712	[illegible]	1,983	−576	[illegible]	−2,147	29,175	
Precipitation	131	[illegible]	555	2,310	[illegible]	[illegible]	[illegible]	0	190	9,530	
Consumptive use	[illegible]	4,735	6,060	7,022	[illegible]	[illegible]	−156	3,485	−1,957	38,705	
Stream-flow depletion:											
Per irrigated acre (9,000 acres)	0.66	[illegible]	[illegible]	[illegible]	0.66	0.22	−0.06	0.39	−0.21	[2] 3.24	[3] 3.39
Consumptive use:											
Per irrigated acre (9,000 acres)	.68	.53	.67	.78	.77	.72	−.01	.39	−.22	[2] 4.31	4.46
Per [illegible]	.35	.27	.35	.40	.39	.37	−.02	.20	−.11	[2] 2.20	[illegible]

[1] Estimated.
[2] [illegible]
[3] Including change in ground-water storage.

shown in table 67. Estimated consumptive use for various types is shown in table 67. The units upon which these estimates are based were selected arbitrarily. The entire area of the tract (21,074 acres) is used in the computations. Estimates of Valley consumptive use range from 53,287 to 61,655 acre-feet for the 21,074 acres. The unit consumptive use ranges from 2.53 acre-feet per acre to 2.93 with an average of 2.73 acre-feet per acre. This average is close to that obtained by application of the inflow-outflow method (2.7 acre-feet per acre).

Comsumptive use in the Middle Valley.—With the data available for Middle Rio Grande Valley, the integration method offers the best present means of estimating consumptive use of water. Hence the average consumptive use in the Middle Rio Grande Conservancy District was determined by this method. The acreage mapped by the Bureau of Agricultural Engineering in 1936 and the estimated unit consumptive use for various crops based on the Bureau's 1936 studies were used in the computations. The acreages of land in the different classifications, the estimated unit consumptive use, and the computed normal Valley consumptive use for the Cochiti, Albuquerque, Belen, and Socorro divisions are shown in tables 68 to 71.

TABLE 67.—*Consumptive use of water in Isleta-Belen area in Middle Rio Grande Valley, N. Mex., as estimated by integration method, using different units*

Type	1936 area	Consumptive use					
	(a)	(c)	(ca)	(c)	(ca)	(c)	(ca)
	Acres	Acre-feet per acre	Acre-feet	Acre-feet per acre	Acre-feet	Acre-feet per acre	Acre-feet
Irrigated land:							
[illegible]	3,088	4.0	12,352	4.5	13,896	3.5	10,808
[illegible]	1,299	3.0	[illegible]	3.0	3,897	2.5	3,248
[illegible]	4,760	2.0	9,520	1.5	7,140	2.0	9,520
Native vegetation:							
[illegible]	5,186	3.0	15,558	2.5	12,965	2.0	10,372
[illegible]	[illegible]	3.5	5,600	3.5	5,600	3.0	4,800
[illegible]	1,572	3.0	4,716	3.0	4,716	2.5	3,930
[illegible]	1,194	5.0	5,970	4.5	5,373	5.5	6,567
[illegible]							
Temporarily out of cropping	477	2.0	[illegible]	2.0	954	2.0	[illegible]
[illegible]	42	2.0	84	2.0	84	2.0	84
Water surface: Pooled, [illegible]	[illegible]	[illegible]	1,496	4.3	1,496	[illegible]	[illegible]
[illegible]	1,508	1.0	1,508	1.0	[illegible]	1.0	[illegible]
Total entire area	21,074	2.93	61,655	[illegible]	[illegible]	2.53	53,287

[1] ca = the product of unit consumptive use in acre-feet per acre (c) by area in acres (a).

TABLE 68.—*Consumptive use of water in Cochiti Division, Middle Rio Grande Conservancy District, New Mexico, as estimated by integration method*

Type of land	1936 area	Consumptive use	
	(a)	(c)	[illegible]
	Acres	Acre-feet per acre	Acre-feet
Irrigated land:			
[illegible]	[illegible]	4.0	2,792
Native hay and pasture	1,474	2.5	3,685
[illegible]	3,036	2.0	6,072
Entire area	[illegible]	[illegible]	[illegible]
Temporarily out of cropping	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
Native vegetation:			
[illegible]	2,628	[illegible]	6,570
[illegible]	4,417	3.0	13,251
[illegible]	4,187	5.0	20,935
Entire area	11,232	3.63	40,756
[illegible]	1,528	4.3	6,570
[illegible]	[illegible]		[illegible]
[illegible]	19,439	3.19	61,916

[1] ca = the product of unit consumptive use in acre-feet per acre (c) by area in acres (a).

The total Valley consumptive use for 187,682 acres in the district was 582,858 acre-feet, and the average unit consumptive use 3.11 acre-feet per acre.

These figures may or may not represent normal use, for should the recently constructed storage, irrigation, and drainage works have their intended effects in altering the present agriculture of the Middle Valley, or should economic conditions reshape it, the water requirements might be much changed.

Table [illegible].—*[illegible], Middle Rio Grande Conservancy District, New Mexico, as esti-[illegible]*

[illegible]	[illegible] (a)	[illegible]	[illegible]
	Acres	Acre-feet per acre	Acre-feet
Irrigated land:			
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	4,241	2.0	[illegible]
[illegible]			
[illegible]	10,487	2.5	26,218
[illegible]	4,968	3.0	14,904
[illegible]	8,040	5.0	40,200
[illegible]	[illegible]	3.46	81,322
[illegible]	5,738	4.3	[illegible]
[illegible]	[illegible]	1.0	921
[illegible]	58,127	3.08	178,832

[1] ca = the product of unit consumptive use in acre-feet per acre (c) by area in acres (a).

Table 70.—*[illegible], Middle Rio Grande Conservancy District, New Mexico, as estimated by integration method*

[illegible]	1936 area	Consumptive use [1]	
	Acres	Acre-feet [illegible]	[illegible]
Irrigated land:			
[illegible]	7,883	[illegible]	31,532
[illegible]	[illegible]	2.5	8,160
[illegible]	12,748	2.0	[illegible]
[illegible]	23,895	2.73	65,188
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]			
[illegible]	[illegible]	[illegible]	66,350
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	4.3	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

Table 71.—*Consumptive use of water in Socorro Division, Middle Rio Grande Conservancy District, New Mexico, as estimated by integration method*

Type of land	[illegible]	[illegible]	
	[illegible]	[illegible]	(ca)
	Acres	Acre-feet per acre	Acre-feet
[illegible]			
[illegible]	1,632	4.0	[illegible]
[illegible]	772	2.5	1,930
[illegible]	4,833	2.0	[illegible]
[illegible]	7,237	2.50	18,124
[illegible]	733	2.0	1,466
[illegible]	993	[illegible]	[illegible]
[illegible]			
[illegible]	4,313	[illegible]	10,782
[illegible]	[illegible]	3.0	[illegible]
[illegible]	[illegible]	5.2	38,802
[illegible]	[illegible]	3.96	58,899
[illegible]	7,850	4.5	35,325
[illegible]	1,379	1.0	1,379
[illegible]	33,072	3.54	117,179

[1] ca = the product of unit consumptive use in acre-feet per acre (c) by area in acres (a).

Soil Moisture Studies—Agricultural Crops

Suitable sites for soil moisture studies in the Middle Rio Grande Valley are very limited as the water table in most sections is relatively high. Plots were selected in a deciduous orchard, an alfalfa field and a vineyard on the farm of J. L. Phillips, approximately 5 miles south of Albuquerque, after careful consideration had been given to the following factors: (a) Absence of a high water table; (b) willingness of farmer to cooperate; (c) uniformity of soil; (d) general condition of crop; (e) conditions affecting water delivery, especially facilities for measurement.

The experimental plots were on Anthony silty clay loam soil underlain, at about 3 feet, by approximately 12 inches of pinkish-gray silty clay. A dense clay layer was encountered between 7 and 10 feet below the surface. The top soil was moderately friable and easily cultivated.

The water for the farm is obtained by pumping with a vertical centrifugal pump with a 6-inch discharge, driven by a 15-horsepower electric motor, from a well 85 feet deep. The water level is normally at 33 feet. The discharge is approximately 540 gallons per minute.

The amount of water applied and the frequency of irrigation was determined by the owner. The water was measured over a 2-foot rectangular weir. During the irrigation season some precipitation occurred. This ranged up to 1.55 inches in single storms and totaled about 5.11 inches.

Soil samples were taken on each plot to a depth of 10 feet before and after irrigation, with some additional sampling between irrigations, to determine the soil-moisture fluctuations and the rate of moisture extrac-

tion by the crops at various depths. All soil samples were taken with the Veihmeyer improved soil tube at definitely established points in the plots. This sampling was done at 6-inch intervals in the first foot and at 1-foot intervals thereafter, to the final depth of 10 feet.

Standard methods were used in weighing and drying the soil samples and in the computation of the moisture percentages. From the moisture percentages thus obtained the amounts of water used by the crops (in acre-inches per acre from each foot of soil) were computed by using the previously discussed formula $D = \frac{MVd}{100}$. (See p. 348.) The total use was then reduced to equivalent uses for 30 days.

The apparent specific gravity (volume-weight) and field capacity of the soil in the various plots are shown in table 72.

Orchard.—The orchard (3.5 acres) was planted in 1929. The ground has a slope of 1 foot in 100 feet. The orchard contains apples, peaches, plums, and quinces, the trees being spaced 24 feet apart in each direction. The trees began to shed their leaves Oct. 20, 1936. Soil samples were taken around a plum tree. The six holes were placed on two lines at right angles to each other. Holes no. 1 and no. 6 were 12 feet from the tree; no. 2 and no. 5, 9 feet; and no. 3 and no. 4, 6 feet.

The results of the soil moisture studies are summarized in tables 73 and 74. Table 73 shows the average moisture content at each sampling, with the dates and quantities of irrigation water applied. In table 74, the moisture percentages have been reduced to acre-inches of water per acre taken by the growing crop from each foot in depth of soil. Soil moisture determinations were made on approximately 540 samples in the orchard.

TABLE 72.—[illegible] Phillips orch[illegible] near Albuquerque, N. Mex., [illegible]

Depth of soil	Orchard		[illegible]		[illegible]	
	Apparent specific gravity	Field capacity (percent)	Apparent specific gravity	Field capacity (percent)	[illegible]	Field capacity [illegible]
First 6 inches	1.35	9.3	1.27	15.1	1.35	11.7
Second 6 inches	1.49	11.0	1.33	23.7	1.40	18.1
Second foot	1.26	19.6	1.20	22.9	1.32	12.7
Third foot	1.27	[illegible]	[illegible]	23.1	1.32	[illegible]
Fourth foot	1.22	17.4	1.33	22.1	1.41	6.0
Fifth foot	1.27	11.3	1.33	17.8	1.38	[illegible]
Sixth foot	1.35	5.3	1.14	22.7	1.35	7.3
Seventh foot	1.43	4.4	1.16	24.2	1.28	13.2
Eighth foot	1.42	[illegible]	1.17	15.8	1.21	17.4
Ninth foot	1.42	5.6	1.23	12.4	1.21	16.6
Average	1.33	10.2	1.23	20.0	1.31	11.8

The soil moisture percentages used for the first 3 feet on May 8 are the values for field capacity. The moisture percentages used for October 10 for the fifth, sixth, seventh, eighth, and ninth foot are equal to those for September 9, since it was found that a heavy rain penetrated the soil only 4 feet.

Vineyard.—The vineyard (6.9 acres) was also planted in 1929. The slope is 1.4 feet in 100 feet. The vines (Alicante) are 8 feet apart. Picking of the grapes on a large scale started October 14, 1936. Samples were taken 4 feet north and south of each of three vines which were 92 feet apart. Soil moisture determinations were made on about 510 samples. Table 75 shows the average moisture content at each sampling. Table 76

TABLE 73.—*Results of soil sampling and irrigation data, Phillips mixed orchard near Albuquerque, N. Mex., season of 1936*

Date of sampling	Average moisture content of the soil, percent											Dates of irrigation	Depth of irrigation water applied, inches
	First 6 inches	Second 6 inches	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot	Seventh foot	Eighth foot	Ninth foot	Tenth foot		
May 8	9.3	11.0	19.6	14.1	20.0	7.7	6.7	5.9	5.8	6.6	14.9		
May 23	4.4	6.4	15.7	12.6	17.4	9.8	4.5	4.0	3.9	5.5	15.5	May 16	8.16
June 2	9.3	11.0	19.6	14.1	17.4	11.3	5.3	4.4	4.4	5.6	15.0	...	...
July 7	5.5	6.2	12.1	8.9	12.2	8.4	4.5	3.9	5.6	8.3	17.7	July 9	3.73
July 28	8.8	11.0	17.1	10.2	13.1	9.8	5.3	4.1	5.1	7.5	...	July 21	3.82
Aug. 7	7.1	9.4	15.8	9.0	9.7	6.3	6.6	5.4	6.1	6.4	...	...	...
Aug. 14	5.6	8.9	14.2	7.9	9.3	6.2	6.3	5.1	6.0	5.7	...	Aug. 31	4.18
Sept. 9	8.1	12.8	21.6	12.2	17.1	7.8	4.8	4.2	4.7	4.5	...	...	...
Oct. 6	12.4	16.1	26.1	12.5	16.8	7.8	4.8	4.2	4.7	4.5		...	

TABLE 74.—*Quantities of water used in intervals between irrigations in Phillips mixed orchard near Albuquerque, N. Mex., season of 1936*

Interval	Soil moisture loss, acre-inches per acre												
	First 6 inches	Second 6 inches	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot	Seventh foot	Eighth foot	Ninth foot	Rain in inches	Total	Calculated loss in 30 days
May 8 to May 23	0.40	0.41	[illegible]	0.23	0.38	−0.32	0.28	0.33	0.32	[illegible]	[illegible]	[illegible]	5.92
June 2 to July 8	.31	[illegible]	1.13	.79	.76	.44	.13	[illegible]	−.21	[illegible]	1.41	4.82	4.14
July 28 to Aug. 14	.26	.19	.44	.35	.55	.55	−.16	−.17	−.15	.31	.40	2.57	[illegible]
Sept. 9 to Oct. 6	−.35	−.30	[illegible]	−.05	[illegible]	[illegible]	[illegible]	0	0	[illegible]	[illegible]	1.65	[illegible]

shows the calculated loss in acre-inches per acre for the period considered and per 30 days.

Alfalfa.—The alfalfa, which has in this region a growing season from about April 15 to about October 10, was planted in the spring of 1933. The stand in 1936 was fair. Samples were taken at three holes on the center line of the field (1.37 acres) 110 feet apart. This field has a slope of 1 foot per 100 feet. All the soil moistures and the dates of sampling are shown in table 77, together with the amounts of irrigation water applied. The calculated uses of water in acre-inches per acre per 30 days are shown in table 78.

Soil Moisture in Native Vegetative Areas

In the summer of 1936 soil samples were taken in typical areas of high water table in the Albuquerque, Belen, and Socorro divisions of the Middle Rio Grande Conservancy District near some of the observation wells of the Geological Survey. The primary purpose of this investigation was to determine the soil characteristics and the amount of water available in the soil above the water table for use of native vegetation.

The samples were taken with a standard soil tube, in 6-inch and 1-foot sections. The depth to ground water, soil type, and vegetative cover were observed when the soil samples were taken.

TABLE 75.—*Results of soil sampling and irrigation data, Phillips vineyard, near Albuquerque, N. Mex., season of 1936*

[illegible]	[illegible] inches	[illegible]	[illegible]	[illegible]	[illegible]	Fifth foot	Sixth [illegible]	Seventh foot	Eighth foot	Ninth foot	Tenth foot	Dates of irrigation	Depth of irrigation [illegible] applied (inches)
[illegible]	[illegible]	24.0	18.2	[illegible]	8.3	5.8	7.8	13.7	15.8	18.7	17.6		
[illegible]		15.6	13.8	12.8	8.3	6.3	7.9	13.0	19.2	20.7	16.9	June 10	3.48
June 18	11.2	[illegible]	13.0	11.4	8.1	9.3	8.4	12.9	[illegible]	21.5	18.5		
July 7	6.5	11.2		10.4	7.5	7.4	9.3	11.9	18.1	18.3	14.4	[illegible]	3.05
July 28	11.7	18.1	12.7	9.4	[illegible]	5.4	7.3	13.2	17.4	[illegible]			
Aug. 6	8.3	19.9	11.4	9.8	6.4	5.8	8.6	14.1	17.3	18.7			
Aug. 13	[illegible]	10.9	10.5	9.1		4.7	8.1	13.6	16.6	19.3		[illegible]	[illegible]
[illegible]	9.2	13.7	10.9	9.4	[illegible]	5.4	7.9	13.7	16.0	17.7			
[illegible]	12.2	11.4	10.6	10.4	[illegible]	[illegible]	[illegible]	8.1	14.3	22.4			

TABLE 76.—*Quantities of water used in intervals between irrigations in Phillips vineyard, near Albuquerque, N. Mex., season 1936*

Interval	Soil moisture loss, acre-inches per acre												
	[illegible]	[illegible]	[illegible]	Third foot	Fourth foot	Fifth [illegible]	Sixth foot	Seventh foot	Eighth [illegible]	Ninth [illegible]	[illegible]	Total	Calculated loss in 30 days
May 9 to June 10	0.41	[illegible]	0.70	0.11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	−0.29	0.68	1.84	1.73
June 18 to July 7	.38	[illegible]	[illegible]	.16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.46	.61	2.73	4.32
July 28 to Aug. 13	[illegible]	[illegible]	.35	[illegible]	[illegible]	.12	[illegible]	[illegible]	[illegible]	−.39	.40	1.47	[illegible]
[illegible]	[illegible]	[illegible]	.05	−.16	[illegible]	.10	[illegible]	[illegible]	.25	−.69	1.41	[illegible]	2.70

TABLE 77.—*Results of soil sampling and irrigation data, Phillips alfalfa field, near Albuquerque, N. Mex., season of 1936*

Dates of sampling	Average moisture content of the soil, percent											Dates of [illegible]	Depth of irrigation water [illegible]
	[illegible] inches	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Ninth [illegible]	Tenth foot		
[illegible]	12.7	[illegible]	23.3	[illegible]	[illegible]	12.1	[illegible]	19.4	12.3	11.4	12.1	June 13	6.00
July 7	[illegible]	[illegible]	22.9	23.1	22.1	17.8	[illegible]	24.2	15.8	12.4	10.7	June 30	6.72
[illegible]	15.1	[illegible]	20.1	21.2	16.7	13.8	22.7	23.6	15.2	12.0		July 27	6.54
[illegible]	11.8	[illegible]	17.1	19.3	12.4	12.1	27.3	23.3	15.2	13.0			
[illegible]	15.1	23.7	22.9	23.1	22.1	17.8	[illegible]	21.2	15.8	12.4		Sept. 1	[illegible]
[illegible]	[illegible]	[illegible]	25.7	19.9	10.2	12.0	24.2	19.5	14.1	12.2			

[illegible] ld capacity as determined July 7.

TABLE 78.—*Quantities of water used in intervals between irrigations in Phillips alfalfa field, near Albuquerque, N. Mex., season of 1936*

Interval	[illegible] moisture loss, acre-[illegible]												
	[illegible]	Second 6 inches	[illegible] foot	[illegible] foot	[illegible] foot	Fifth foot	Sixth foot	Seventh foot	[illegible] foot	Ninth foot	[illegible] inches	Total loss	Calcu-[illegible] in 30 [illegible]
Aug. 6 to Aug. 13	0.25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.00	[illegible]
Sept. 9 to Oct. 6	−.24	.10	−.10	[illegible]	[illegible]	.93	−.21	.65	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The percent of moisture in the soil at the time of sampling, the saturation percentage, the apparent specific gravity (volume-weight), the real specific gravity and the porosity were determined in the laboratory. In addition, moisture-equivalent determinations were made of the samples taken in Socorro division. Tables 79 to 81 give some of the results in each division.

TABLE 79.—*Results of some of the soil moisture studies, Albuquerque division, Middle Rio Grande Valley, N. Mex., July 1936*

Depth of sample (feet)	Field moisture content (percent)	Saturation (percent)	Apparent specific gravity	Real specific gravity	Porosity (percent)	Ratio field moisture to saturation
HOLE NO. 5						
0.0 to 0.5	3.6	28.7	1.43	2.60	40.9	12.5
0.5 to 1.0	6.7	30.4	1.74	2.63	52.9	22.0
1.0 to 2.0	22.1	37.7	1.39	2.62	52.4	58.7
2.0 to 3.0	18.2	27.3	1.20	2.64	32.7	67.0
3.0 to 4.0	26.5	26.5	1.42	2.62	37.4	100.0
4.0 to 5.0	33.6	42.2	1.22	2.48	51.6	79.6
HOLE NO. 6						
0.0 to 0.5	18.7	37.2	1.08	2.53	49.2	50.3
0.5 to 1.0	10.4	26.4	1.89	2.59	50.4	39.4
1.0 to 2.0	8.5	21.9	1.53	2.63	33.7	38.8
2.0 to 3.0	12.5	20.0	......	2.66	......	62.6
HOLE NO. E2-6						
0.0 to 0.5	24.7	62.2		2.44		39.7
0.5 to 1.0	20.0	39.9	1.25	2.57	50.1	50.1
1.0 to 2.0	19.0	31.3	1.35	2.64	42.4	60.7
2.0 to 3.0	13.9	27.4	1.03	2.64	28.2	50.8
3.0 to 4.0	23.8	23.8	1.75	26.7	41.5	100.0

NOTE.—Hole no. 5, depth to water table, 5.2 feet; vegetation, salt grass. Hole no. 6, depth to water table, 3.0 feet; vegetation, salt grass. Hole no. E2-6, depth to water table, 4.4 feet; vegetation, weeds.

TABLE 80.—*Results of some of the soil moisture studies, Belen division, Middle Rio Grande Valley, N. Mex., July 1936*

Depth of sample (feet)	Field moisture content (percent)	Saturation (percent)	Apparent specific gravity	Real specific gravity	Porosity (percent)	Ratio field moisture to saturation
HOLE NO. 1W-53						
0.0 to 0.5	6.7	32.4	1.41	2.58	45.8	20.7
0.5 to 1.0	5.3	37.3	1.35	2.58	50.2	14.2
1.0 to 2.0	7.1	36.5	1.41	2.60	51.5	19.4
2.0 to 3.0	31.5	49.6	.97	......	48.0	63.5
3.0 to 4.0	23.9	23.9		2.65	......	100.0
HOLE NO. 4W-53						
0.0 to 0.5	12.6	48.5	1.37	2.56	66.7	26.0
0.5 to 1.0	16.5	46.9	1.39	2.56	65.3	35.2
1.0 to 2.0	15.3	35.7	1.44	2.58	51.4	42.8
2.0 to 3.0	17.1	45.1	1.26		56.8	38.0
3.0 to 4.0	38.1	59.8	1.16	2.51	69.3	63.7
4.0 to 5.0	28.0	38.0	1.19		45.3	
5.0 to 6.0	26.9	26.9		2.63		100.0
HOLE NO. 4E-453						
0.0 to 0.5	16.9	43.5	1.22	2.61	53.1	38.9
0.5 to 1.0	19.2	45.0	1.55	2.61	69.7	42.7
1.0 to 2.0	18.2	29.9	1.66	2.60	59.5	[illegible]
2.0 to 3.0	32.7	41.5	1.24		51.5	78.8
3.0 to 4.0	34.2	34.2		2.55		100.0

NOTE.—Hole no.1 W-53, depth to water table, 4.3 feet; vegetation, bosque and salt grass. Hole no. 4W-53, depth to water table, 5.8 feet; vegetation, salt grass. Hole no. 4E-453, depth to water table, 33 feet; vegetation, salt grass.

TABLE 81.—*Results of some of the soil moisture studies in Socorro [illegible], Middle Rio Grande Valley, N. Mex., [illegible]*

Depth of sample, feet	Hole no. 1: Field moisture content (percent)	Hole no. 1: Apparent specific gravity	Hole no. 1: Moisture equivalent (percent)[1]	Hole no. 1: Porosity, (percent)	Hole no. 2: Field moisture content (percent)	Hole no. 2: Apparent specific gravity	Hole no. 2: Moisture equivalent (percent)	Hole no. 2: Porosity (percent)
0.0 to 0.5	14.0	1.08	18.13	59.6	31.0	1.44	13.96	[illegible]
0.5 to 1.0	5.5	1.08	5.04		21.9	1.44	10.97	
1.0 to 1.5	4.3	1.33	2.20	[illegible]	41.0	1.07	31.29	[illegible]
1.5 to 2.0	3.2	1.33	1.44		[illegible]	1.07	38.40	
2.0 to 2.5	4.1	1.66	1.40	[illegible]	47.9	1.14	35.00	[illegible]
2.5 to 3.0	5.8	1.66	1.34		52.2	1.14	37.22	
3.0 to 3.5	18.7	1.38	2.89	48.1	66.9		[illegible]	
3.5 to 4.0	16.1	1.38	1.94		79.3		[illegible]	
4.0 to 4.5	18.9	1.70	1.84	35.8				
4.5 to 5.0	24.4	1.70	2.54					
5.0 to 5.5	24.7	1.57	2.47	41.2				
5.5 to 6.0	26.5	1.57	2.48					

[1] Moisture equivalent determinations below the first foot are of questionable value because of sandy nature of soil.

Alfalfa Tank Experiments

A station for the study of the consumptive use of water by alfalfa grown in tanks was established on June 8, 1936, in a 10-acre alfalfa field of the Los Poblanos Ranch, approximately 5 miles north of Albuquerque. The alfalfa was planted in the spring of 1935.

The climatic conditions at the station are representative of the Middle Rio Grande Valley. Depths to the water table in the surrounding fields ranged from 4½ feet to 5½ feet. The soil is Gila loam. Characteristics of the soil in the field near the tanks are shown in table 82.

TABLE 82.—*Field capacity, apparent specific gravity, and pore space of Gila loam soil at Los Poblanos ranch, near Albuquerque, Middle Rio Grande Valley, N. Mex., 1936*

Depth in feet	Type of soil	Field capacity (percent)	Apparent specific gravity	Porosity (percent)
0.0 to 0.5	Silty clay loam	30.4	1.38	48.0
0.5 to 1.0	do	[illegible]	[illegible]	48.5
1.0 to 2.0	Fine sandy loam	11.6	1.36	48.8
2.0 to 3.0	Loam	20.5	1.26	52.5
3.0 to 4.0	do	32.0	1.26	52.5
4.0 to 5.0	Fine sandy loam	24.0	1.24	53.3
5.0 to 6.0	Sandy loam	23.7	1.36	48.8
6.0 to 7.0	Fine sand	21.4	1.60	39.8
7.0 to 8.0	do	23.7	1.66	37.5
Average		23.2	1.39	47.7

Installation of equipment.—A standard 8-inch rain gage and two soil tanks, each connected to a Mariotte apparatus were installed at the station. The soil tanks were the double type with an annular space between the inner and outer shells (3), (4). The inner tank, 23³⁄₁₆ inches in diameter by 6 feet deep, was suspended in the outer tank (diameter 25½ inches) by means of a heavy angle-iron rim around the top. The bottom of the inner tank was removable and bolted in place by long rods, to the supporting top rim. The inner tank

held the soil, the outer being a reservoir for water which passed into the soil through the bottom plate and the inner shell perforations.

Since it was deemed desirable to have the same soil structure and growth of alfalfa in the tanks as in the surrounding field, each tank was filled by forcing the bottomless inner shell into the ground, so cutting a core of soil of the same diameter as that of the tank to a 6-foot depth. The earth around the tank shell was excavated as the filling of the tank proceeded.

A tripod was erected by means of which the 6-foot tank could be hoisted above ground. It was also used in driving the inner tank into the soil. A heavy timber was placed across the top of the tank, and a weight hoisted by means of a block and tackle attached to the tripod, was allowed to fall on the timber, thereby forcing the tank down. Friction of soil against the outside of the tank was relieved by excavating around the tank, this excavation generally being kept a few inches ahead of the cutting edge of the tank.

When the inner tank shell was filled, the soil column was cut off by walking the shell after having connected it, by means of a strong cable, to a block and tackle fastened on the tripod. As soon as sufficient clearance was obtained, the bottom plate of the inner tank was pushed across the bottom edge and bolted to the angle-iron rim at the top of the tank. This method was found more satisfactory than jacking the bottom plate across the bottom edge of the tank as had been done in some installations in the past (4). The inner tank was then hoisted above ground by means of the chain block. The outer shell was next set in place in the excavation, and the inner shell, with its soil content, was lowered into the outer, where it hung suspended from the heavy iron rim around the top. The tanks were designated as the north tank and the south tank.

The soil columns in both tanks were then completely saturated. After 36 hours the water was pumped from the annular space. Twelve hours later the water level had stabilized at a depth of 58 inches beneath the ground surface in the north tank and at 60 inches in the south tank. The alfalfa in the tank was affected very little by this procedure.

Operation of tanks.—The 5-gallon Mariotte supply bottles with which the tanks were equipped stood in an inverted position in wooden boxes about 3 feet above the ground so that their shadows would not fall on the tanks. Water was conducted through a rubber hose and through a ¼-inch pipe into the annular space between the inner and outer shells of each tank. The lower end of the pipe was placed so as to maintain the water level at 4½ feet below the ground surface. When water was withdrawn by the plants from the soil column, the water level in the annular space would drop and air would enter the pipe and the bottle. The resulting unbalanced air pressure would force water out of the bottle until the end of the pipe was again submerged and equilibrium established.

On the evenings of the fifteenth and last days of each month the soil columns were completely saturated. About 80 percent of the water was applied as subirrigation by filling the annular space, and 20 percent by flooding the soil surface. The water was pumped down to the desired level the following morning. While it is more desirable to subirrigate only, so as to expel all the air in the soil, flooding was used to saturate the soil quickly in order, so far as possible, to eliminate evapotranspirational losses during observations. All the water added or withdrawn was measured (see p. 348).

Results.—Table 83 shows the consumptive use of water, the temperatures at Albuquerque, and the precipitation, arranged by periods.

Over the entire period from June 26 to October 31, the average consumptive use of the two tanks was 30.35 inches, which is equivalent to 1.67 inches per 7-day

TABLE 83.—*Weekly and monthly consumptive use of water for alfalfa tanks with water table at an average depth of 4½ feet, Los Poblano Ranch, near Albuquerque, N. Mex., June 26 to Oct. 31, 1936*

[illegible]	[illegible]	[illegible]			[illegible]			[illegible]			[illegible]	Mean temperature, °F.[3]			[illegible] irriga-[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	Per [illegible]	Per 30 [illegible]	For [illegible]	Per [illegible]	[illegible] days		Mean [illegible]	Mean [illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	11.94	5.29	1.95	8.35	6.24	[illegible]	[illegible]	[illegible]	[illegible]	61.3	76.6	June 25
[illegible]	[illegible]	[illegible]	[illegible]	8.91	4.44	1.83	[illegible]	[illegible]	[illegible]	8.38	.4[illegible]	[illegible]	[illegible]	[illegible]	Aug. 1
[illegible]	[illegible]	[illegible]	2.77	11.89	[illegible]	3.20	[illegible]	[illegible]	[illegible]	12.80	[illegible]	[illegible]	[illegible]	[illegible]	Aug. 15
[illegible]	[illegible]	3.76	1.55	[illegible]	4.70	[illegible]	[illegible]	[illegible]	[illegible]	7.47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1.37	5.88	2.61	1.22	[illegible]	[illegible]	[illegible]	[illegible]	.41	[illegible]	[illegible]	71.6	Sept. 15
[illegible]	[illegible]	2.30	[illegible]	[illegible]	2.46	1.15	4.92	2.38	1.11	4.76	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1.57	6.74	[illegible]	[illegible]	5.53	[illegible]	1.43	6.14	[illegible]	74.1	[illegible]	58.3	Oct. 16
[illegible]	14	.39	.20	.84	1.03	.52	2.21	.71	.36	1.53	.16	[illegible]	[illegible]	[illegible]	[illegible]

period and to 7.17 inches per 30-day period. If the period of use of water is extended back to April 15, the beginning of the growing season of alfalfa, the use computed on the basis of mean temperatures would be 11.5 inches.

The alfalfa in the field was cut four times with two irrigations for each cutting. In each irrigation approximately 6.1 acre-inches per acre of water was applied, which gave a seasonal application of approximately 49 acre-inches per acre.

The alfalfa in the tanks was cut on June 27, August 22, and October 15. One crop was lost on July 14, being destroyed by livestock. Each crop was weighed green and oven-dry. The weights are given in table 84.

The amount of water required to produce 1 pound of dry alfalfa was computed for the crops harvested on August 22 and October 15. The water necessary to produce these crops was reduced from acre-inches to pounds and corrected for evaporation losses in the top 6 inches of soil. The water requirements for the four crops (two from each tank) were averaged and found to be 1,140 pounds of water per pound of dry alfalfa.

TABLE 84.—*Yield of alfalfa grown in tanks, Los Poblanos Ranch, near Albuquerque, N. Mex.*

Date	Weight of crop [illegible]			
	North tank		South tank	
	Green	Oven-dry	Green	Oven-dry
June 27	164.0	36.0	329.0	71.0
July 14[1]				
Aug. 22	162.5	44.0	281.0	77.0
Oct. 15	[illegible]	52.0	231.0	55.0

[1] Lost.

Native Vegetation and Evaporation Experiments

Water-loving vegetation and the presence of a high ground water throughout much of the area of natural growth in the Middle Valley result in the consumption of large quantities of water. Salt grass, willows, tules, and cottonwoods are the principal users on account of their greater acreage. E. B. Debler and C. C. Elder recognized this fact when they established a tank experiment station at Los Griegos (p. 340). To extend these previous investigations the Bureau of Agricultural Engineering established an evapo-transpiration and evaporation station at Isleta and evaporation stations at El Vado Dam and Socorro.

Isleta station.[7]—The Isleta station was instituted by the Bureau of Agricultural Engineering at Isleta (about 13 miles south of Albuquerque) during May 1936. It was located on the east side of Rio Grande adjacent to the Isleta diversion dam of the Middle Rio Grande Conservancy District, in a low, moist area containing a variety of water-loving plants including sedges, tules (cattails), salt grass, and willows. Data on tank installation at the Isleta station are given in table 85, and a sketch of the station is shown in figure 84. Here as elsewhere with similar work, Mariotte apparatus was used to supply water to vegetation tanks as well as keep the water surface in the tank at a constant level (4). The method of using the apparatus is indicated in figure 85.

Each of the vegetation tanks was placed in a surrounding of natural growth of the same species (that is, in its natural environment), so that consumptive use of water would presumably be the same as for similar growth outside the tank. In previous investigations it has been found that all tank vegetation must be protected from the elements by surrounding growth of the same species.[8]

Since a considerable area in the Middle Rio Grande Valley is occupied by swamp growth, a study of con-

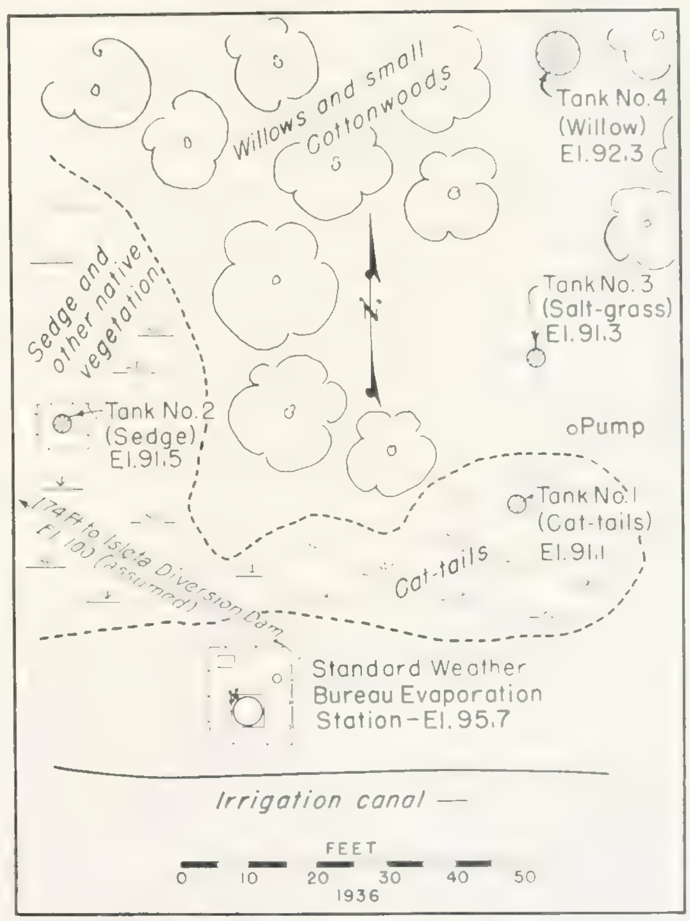


FIGURE 84.—Plan of Isleta Station, N. Mex., 19[illegible]

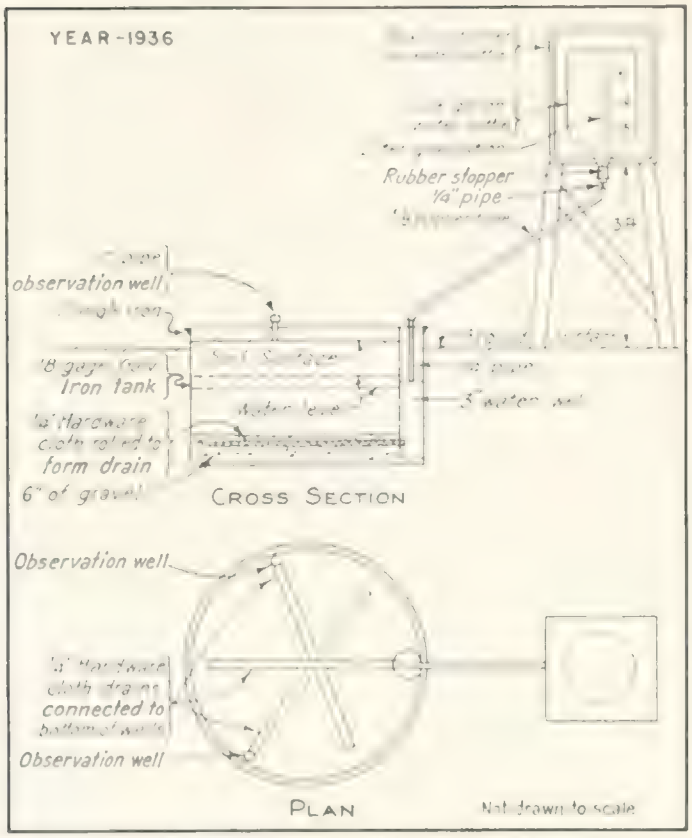
[7] Discussion of Isleta station results was prepared principally by [illegible], associate irrigation engineer, Bureau of Agricultural Engineering.

[8] Tules, for instance, growing in isolated tanks use immense quantities of water daily during the growing season—frequently an acre-inch per acre per day for weeks at a time. In fact, there is a record in the Santa Ana Valley, Calif., of a maximum consumptive use of 3.6 inches of depth in a single 24-hour period by tules in an isolated tank. Obviously, such water use by plant growth is abnormal, otherwise tule swamps would recede and streams dry up at the source (3), (4).

TABLE 85.—*Installation data on tanks used at Isleta station, Middle Rio Grande Valley, N. Mex., 1936*

Tank number	[illegible] (inches)	[illegible]	[illegible]	Ending	Common	[illegible]	[illegible] to water table in [illegible]
[illegible]	[illegible]	[illegible]	[illegible]	November 1936.	Cattail.	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	48	[illegible]	[illegible]	do.	[illegible]	[illegible]	[illegible]

[illegible]



sumptive use of water by cattails growing in water was made at the Isleta station. This growth was transplanted into a tank placed in a swamp area where it could be protected from sun and wind by surrounding growth of the same species. Reference to figure 84 shows the relation of the various tanks to surrounding natural vegetation. Tables 86 and 87 summarize weekly and monthly use of water by cattails, sedges, salt grass, and willows, with pertinent meteorological data.

Comparison of consumptive use by cattails at Isleta (in 1936) with water use by cattails (tules) at Los Griegos (in 1928) discloses a greater loss at Isleta. Consumptive use by cattails during June to September, inclusive, 1936, at Isleta was 60.33 acre-inches per acre as compared with 42.16 acre-inches per acre for tules at Los Griegos for the same months in 1928. (See table 40.)

Consumptive use by sedge growing in water was likewise determined, and apparently there are no other data on use of water by such vegetation in the Rio Grande Valley. Consumptive use during the 6-month period June to November, inclusive, 1936, amounted to 50.06 acre-inches per acre, identifying this growth as a water-loving species.

Consumptive use of water by salt grass at Isleta during the months June to November, inclusive, 1936,

does not compare favorably with consumptive use by similar vegetation at Los Griegos for the same months in 1927. The salt grass tank at Isleta used 23.47 acre-inches with an average depth to water of 7.7 inches, whereas at Los Griegos the total use was 34.56 acre-inches with depth of 5.0 inches. In a comparison of contributing factors, the difference in depth to water does not account for the increased consumptive use; the average hourly wind movement was approximately the same at both places, while mean temperature at Isleta was 7 percent higher than that at Los Griegos. A comparison of evaporation at the two stations shows Isleta to have the smaller amount by about 1 percent. Hence the differences in consumptive use are attributable to factors other than meteorological. The stations were alike in that they were located in native vegetation with high ground water, but differed in size of soil tanks and surroundings. At Los Griegos the salt grass tank was nominally 4 feet in diameter; at Isleta, 2 feet. At Los Griegos there was flat, open country without obstruction to wind movement, whereas at Isleta willows and brush grew in the vicinity of the soil tanks. How-

TABLE 86.—*Weekly consumptive use of water, evaporation, and meteorological data of Isleta station, Middle Rio Grande Valley, N. Mex. season of 1936*

Week ending—	Consumptive use of water in inches				Average depth to water table (inches)		Meteorological data							
	Tank no. 1	Tank no. 2	Tank no. 3	Tank no. 4	Tank no. 3	Tank no. 4	Evaporation, inches (Weather Bureau pan)	Temperature (°F.)[2]			Precipitation (inches)	Wind movement		Average relative humidity at Albuquerque (percent)
	Cattails in water	Sedge in water	Salt grass	Willow	Salt grass	Willow		Mean maximum	Mean minimum	Mean		Total miles	Average miles per hour	
June 1	2.54	1.90					2.31	82	52	67	0.72			[illegible]
June 8	3.56	2.00	1.24	1.26	10.8	11.4	2.81	87	50	69	0			21
June 15	3.32	1.91	1.34	.70	7.3	14.6	[3] 2.44	91	57	74	.18			48
June 22	4.15	2.20	1.32	.96	8.9	15.0	[3] 2.77	[illegible]	53	74	0			30
June 29	3.79	2.25	1.19	.82	11.3	12.4	2.44	92	63	78	.20			42
July 6	3.57	2.40	1.23	.86	11.6	13.2	2.38	96	61	78	0	[illegible]	[illegible]	30
July 13	3.84	2.30	1.39	[3] 1.08	4.3	5.9	2.34	89	61	75	1.52	423	2.52	60
July 20	3.60	2.69	1.41	[3] 1.06	7.5	8.3	2.31	93	64	78	.06	370	2.20	40
July 27	4.18	3.22	1.43	.89	10.5	11.3	2.22	93	62	78	0	324	1.93	35
Aug. 3	3.82	2.16	1.24	1.03	10.8	11.0	2.10	89	64	76	.07	366	2.18	[illegible]
Aug. 10	3.83	3.78	1.26	.96	12.3	13.6	2.03	95	61	78	0	281	1.67	44
Aug. 17	4.34	4.34	1.47	1.13	11.2	12.8	2.34	97	61	79	.03	311	1.85	[illegible]
Aug. 24	3.09	1.94	1.09	1.08	4.7	12.5	1.81	89	60	74	.53	275	[illegible]	47
Aug. 31	3.75	4.64	1.12	1.09	9.4	13.7	2.06	90	62	76	.05	417	2.48	45
Sept. 7	3.51	2.07	1.12	1.08	11.5	7.3	1.81	90	58	74	.02	343	2.04	44
Sept. 14	3.30	1.77	[3] .93	[3] 1.09	1.4	12.1	1.63	85	59	72	1.24	146	.87	[illegible]
Sept. 21	2.53	1.75	[3] .85	[3] 1.00	.9	12.1	1.50	85	56	70	.40	281	1.67	54
Sept. 28	1.89	1.71	[3] .91	[3] .83	5.1	2.9	1.60	75	55	65	1.45	451	2.68	61
Oct. 5	1.47	1.21	[3] .38	[3] .89	−1.1	3.8	1.06	73	40	56	0	256	1.52	54
Oct. 12	1.28	1.22	[3] .41	.67	.5	14.3	1.16	79	41	60	0	337	2.00	47
Oct. 19	1.20	1.07	.40	.82	9.9	11.0	1.09	80	44	62	0	294	1.75	41
Oct. 26	.75	.78	.37	.67	11.2	9.0	.87	64	42	53	.29	588	3.50	66
Nov. 2	.72	.80	.30	.46	12.6	13.0	.88	67	39	53	0	524	3.12	[illegible]
Nov. 9	.61	.55	.22	.36			.78	54	24	39	0	519	3.09	
Nov. 16	.49	.45	.20	.35			.74	64	24	44	0	884	5.26	
Nov. 23	.68	.54	.14	.32			.94	60	30	45	0	710	4.23	
Nov. 30	.51	.38	.14	.17			.24	55	23	39	0	789	4.76	
Dec. 1	.07	.07	.02	.03								51	2.12	

[1] Results doubtful from Aug. 3 to Aug. 31, as tank was tampered with.
[2] Weather Bureau records at Albuquerque from May 19 to June 15 and Nov. 2 to Dec. 1.
[3] Estimated use, based on period of observation and evaporation records.

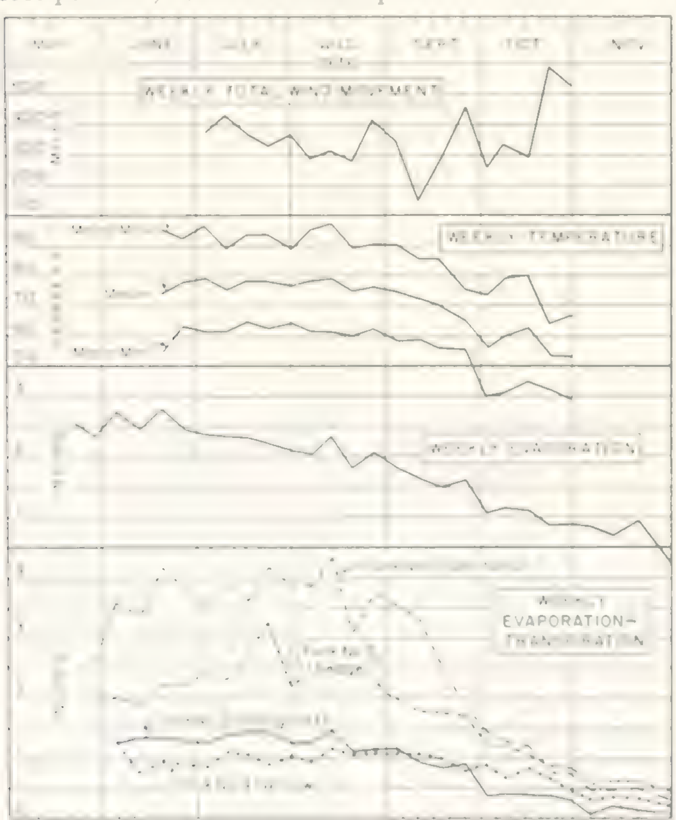
TABLE 87.—*Summary of monthly consumptive use of water, evaporation, and meteorological data of Isleta station, Middle Rio Grande Valley, N. Mex., season of 1936*

Month	Consumptive use of water in inches				Average depth to water table (inches)		Meteorological data							
	Tank no. 1	Tank no. 2	Tank no. 3	Tank no. 4	Tank no. 3	Tank no. 4	Evaporation, inches (Weather Bureau pan)	Temperature ° F.[1]			Precipitation, inches	Wind movement		Average relative humidity at Albuquerque (percent)
	Cattails in water	Sedge in water	Salt grass	Willow	Salt grass	Willow		Mean maximum	Mean minimum	Mean		Total miles	Average miles per hour	
June	15.58	8.98	5.46	3.77	9.6	13.4	11.07	91	56	74	0.38			36
July	16.98	11.45	6.07	4.24	8.5	9.7	10.05	92	62	77	1.58	1,644	2.21	42
August	16.52	[2] 15.57	5.59	[illegible]	9.7	12.7	9.05	92	61	76	[illegible]	[illegible]	1.91	[illegible]
September	11.25	7.39	[3] 3.81	4.18	5.5	8.6	6.62	82	55	68	3.11	[illegible]	1.78	[illegible]
October	4.82	4.54	1.75	2.92	5.1	9.5	4.60	73	42	[illegible]	.29	1,739	2.34	[illegible]
November	2.52	2.13	.79	1.34			2.95	[illegible]	25	42	[4] T	3,124	4.34	
Total	67.67	50.06	23.47	21.25			44.34				6.04			
Average					7.7	10.8		82	50	[illegible]			2.52	[illegible]

[1] Weather Bureau records at Albuquerque from May 19 to June 15 and from Nov. to Dec. 1.
[2] Tank tampered with, results doubtful.
[3] Estimated use, based on period of observations and evaporation records.
[4] Trace.

[illegible] brush growing immediately west of the salt grass tank cast shade on the tank during late afternoons. Thus, the 1936 results show a minimum use of water rather than an average use.

A test was also made of the quantity of water consumed by a clump of willows (6 to 8 feet high) growing in a tank 6 feet in diameter, the tank being set in a thicket of the same species. The water table in the willow tank fluctuated slightly throughout the season with an average depth for the 5 months of record of 10.8 inches, which was close to the ground-water levels outside the tank. Two of the smaller plants died from the shock of transplanting but the large plant flourished. The total consumptive use during the period June to November, inclusive, 1936, was 21.25 acre-inches per acre, which was less than 50 percent of the evaporation from a Weather Bureau pan. While the results indicate the use of water by scattered willow plants they are not representative of the denser growths along the river. The latter usually grow to heights of from 7 to 10 feet and to at least twice the thickness. Thus maximum use of water by willows growing along the Rio Grande will probably be double the amount shown by the Isleta tank, or approximately 42 inches (3.5 acre-feet per acre) for the 6-month period.



[illegible] N. Mex.

Summarizing vegetative use of water at Isleta for the [illegible] used 67.67 acre-inches per acre, sedge 50.06 acre-inches, salt grass 23.47 acre-inches, and willows 21.25 acre-inches per acre. Evaporation from a Weather Bureau pan amounted to 44.34 inches. Compared with evaporation from a free water surface, cattails and sedge are extravagant users of water, while salt grass and willows are more economical—a conclusion supported by similar investigations elsewhere. The weekly variations in use of water, evaporation, temperature, and wind movement are illustrated in figure 188.

El Vado Dam evaporation station.—In June 1936 this station was installed by the Bureau of Agricultural Engineering in cooperation with the Weather Bureau and Middle Rio Grande Conservancy District. The station is located on the high ground adjacent to El Vado Dam, in line with and at approximately the same elevation as the crest produced to the east.

This is a class A station, equipped as follows:

(*a*) Standard Weather Bureau evaporation pan (diameter 4 feet).
[illegible]
(*c*) Thermometers, maximum and minimum.
(*d*) Anemometer, Weather Bureau type (4-cup).
(*e*) Standard rain gage (8-inch).
(*f*) Instrument shelter, cotton region type.

Daily observations were made at 6 a. m., of evaporation, wind movement, maximum and minimum temperatures, and general weather conditions representing daylight hours.

Table 88 shows weekly and monthly evaporation and meteorological data at El Vado Dam station.

Socorro evaporation station.—This station was located in an open space in the Middle Rio Grande Conservancy District yard at Socorro. Early in June 1936 the Bureau of Agricultural Engineering established this station on a small plot furnished by the Conservancy District in cooperation with the Division of Ground Water, Geological Survey. Following is a list of equipment installed:

(*a*) Standard Weather Bureau evaporation pan (diameter 4 feet).
[illegible]
(*c*) Standard rain gage (8-inch)

Observations were made twice daily—once at 8 a. m. and once at 5 p. m.—by Walter E. Herkenhoff of the Division of Ground Water, Geological Survey. These observations consisted of measuring the water level in evaporation pan and recording hook gage readings and measuring and recording the amount of rainfall, if any. Also, a general statement of weather conditions for the day was recorded.

[illegible] that the water level was kept between 2 and 3 inches

TABLE 88.—*Weekly and monthly evaporation and meteorological data at El Vado Dam evaporation station,[1] season of 1936*

Period	Evaporation (inches)	Temperature (°F.) Mean maximum	Mean minimum	Mean	Rain (inches)	Snow (inches)
Week ending—						
June 22	[illegible]	[illegible]	[illegible]	[illegible]	0.02	
June 29	[illegible]	90	[illegible]	70	.13	
Month of June	[illegible]					
Week ending—						
July 6	[illegible]	88	[illegible]	65	0	
July 13	2.69	84	[illegible]	65	1.64	
July 20	1.99	88	[illegible]	67	.06	
July 27	1.99	89	[illegible]	68	.56	
Month of July	[illegible]	87	45	66	2.26	
Week ending—						
Aug. 3	1.81	85	49	67	.38	
Aug. 10	1.43	83	48	[illegible]	.48	
Aug. 17	2.07	90	46	68	.15	
Aug. 24	1.54	83	44	64	1.24	
Aug. 31	1.96	84	47	65	.78	
Month of August	7.89	85	47	66	3.00	
Week ending—						
Sept. 7	1.61	77	41	59	.11	
Sept. 14	1.18	80	41	60	.18	
Sept. 21	1.41	76	36	56	2.44	
Sept. 28	1.58	69	35	52	1.55	
Month of September	6.18	75	34	56	4.18	0.25
Week ending—						
Oct. 5	1.20	59	26	42	.22	
Oct. 12	.95	65	24	44	.25	
Oct. 19	1.19	71	26	48	0	
Oct. 26	.42	57	28	42	.71	
Month of October	3.64	63	27	45	1.48	.50
Week ending—						
Nov. 2	[2].52	[illegible]	[illegible]	42	.82	

[1] Conducted by Bureau of Agricultural Engineering in cooperation with Weather Bureau and Middle Rio Grande Conservancy District. Standard Weather Bureau pan.
[2] Estimated.

from the top of the pan. The pan was emptied and cleaned as often as necessary to keep the water clear. Hook gage readings were taken before and after each filling or cleaning.

Table 89 shows weekly and monthly evaporation and meteorological data at the Socorro station.

TABLE 89.—*Weekly and monthly evaporation and meteorological data at Socorro evaporation station,[1] season of 1936*

Period	Evaporation (inches)	Temperature (°F.) Mean maximum	Mean Minimum	Mean	Precipitation (inches)
Week ending—					
June 8	2.93	92.9	[illegible]	71.3	0
June 15	2.82	99.6	55.0	77.3	.18
June 22	2.89	100.6	58.4	[illegible]	0
June 29	2.80	99.6	59.9	[illegible]	[illegible]
Month, June	12.17	98.2	[illegible]	77.4	.71
Week ending—					
July 6	[illegible]	98.6	60.1	79.4	.01
July 13	2.69	94.4	61.6	[illegible]	1.35
July 20	2.09	97.0	61.3	79.2	.43
July 27	2.31	98.4	61.9	80.2	.02
Month, July	10.60	96.7	[illegible]	68.1	[illegible]
Week ending—					
Aug. 3	[illegible]	95.3	[illegible]	79.9	[illegible]
Aug. 10	2.30	97.1	60.6	78.9	[illegible]
Aug. 17	2.44	101.1	[illegible]	79.2	[illegible]
Aug. 24	2.09	94.1	61.3	77.7	.14
Aug. 31	1.69	92.1	59.1	75.6	.07
Month, August	9.27	95.9	60.0	78.0	.21
Week ending—					
Sept. 7	1.84	[illegible]	57	[illegible]	[illegible]
Sept. 14	1.67	90	[illegible]	74	.59
Sept. 21	1.45	85	56	70	.06
Sept. 28	1.08	76	49	62	1.64
Month, September	6.19	85	54	70	2.29
Week ending—					
Oct. 5	1.14	77	42	[illegible]	0
Oct. 12	1.17	77	37	57	.01
Oct. 19	1.27	82	42	62	0
Oct. 26	.70	65	[illegible]	[illegible]	.08
Month, October	4.64	75	[illegible]	58	.09
Week ending—					
Nov. 2	1.00	69	[illegible]	[illegible]	[illegible]
Nov. 9	.89				[illegible]
Nov. 16	.83				[illegible]
Nov. 23	.85				[illegible]
Nov. 30	.43				.03
Month, November	3.35				.03
Week ending—					
Dec. 7	.49				.17
Dec. 14	.71				0

[1] Conducted by Bureau of Agricultural Engineering in cooperation with United States Geological Survey. Standard Weather Bureau pan.

Lower Valley

The Lower Valley consists of a series of valleys extending from Elephant Butte Reservoir to Fort Quitman. (See p. 298 and fig. 75 and pls. 18–22, incl.)

Water is supplied by the Rio Grande project, built and operated by the Bureau of Reclamation. The project comprises the Elephant Butte Reservoir and dam, several diversion dams, distributing canals and laterals, and an extensive system of open drains to remove excess ground water and reduce alkali damage. The United States is required to furnish 60,000 acre-feet annually to Mexico in compliance with the terms of a treaty between the United States and Mexico signed May 21, 1906.

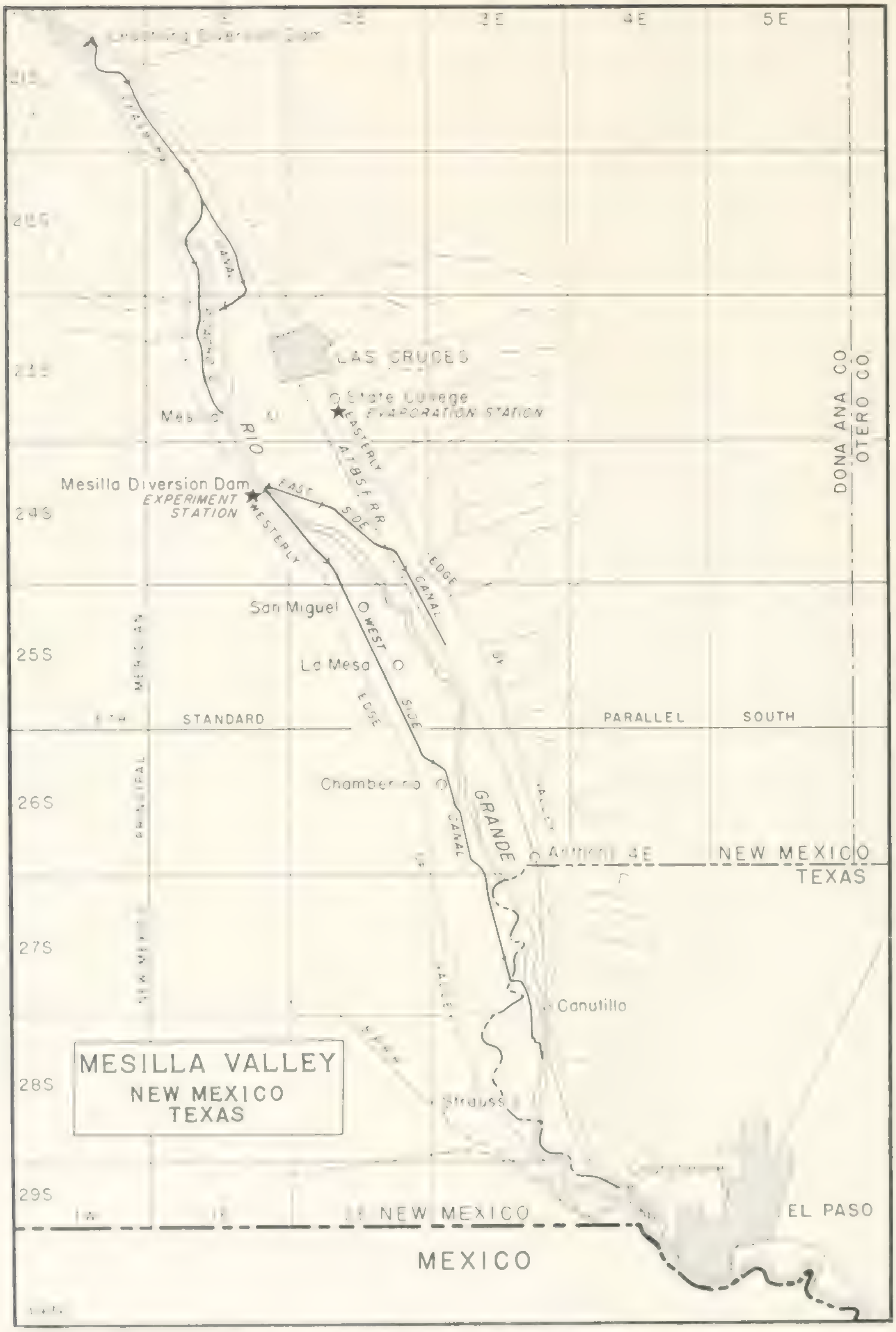
The climate of the section is characteristically arid, with cool nights, but high temperatures during the day. Table 21 shows that the average length of growing season for the Valley ranges from 200 days to 241 days. The mean relative humidity is low. There are very few cloudy days and but little rainfall. These factors contribute to a high evaporation rate.

The average annual rainfall is only 8 to 10 inches per year, about two-thirds coming during the growing season. However, only a portion of this rainfall becomes available for crop use, since much of it occurs in light showers and is lost (consumed) by evaporation before it penetrates to the root zone.

Long time records for temperatures and precipitation have been shown heretofore. (See p. 321.) Table 90 gives the mean temperatures and precipitation for 1936 at El Paso, State College, and Elephant Butte Dam.

The soils of the Valley are alluvial deposit and are extremely variable in texture. (See p. 321.)

Early in April 1936 a preliminary survey was made, and at a conference with representatives of New Mexico and Texas it was agreed that consumptive-use-of-water



5E
LAS CRUCES
State College
EVAPORATION STATION
Mesilla
RIO
EASTERLY
A.T.&S.F. RR.
Mesilla Diversion Dam
EXPERIMENT
STATION
EAST
SIDE
WESTERLY
EDGE
CANAL
San Miguel
WEST
La Mesa
SIDE
EDGE
STANDARD
PARALLEL
SOUTH
Chamberino
CANAL
GRANDE
NEW MEXICO
TEXAS
Canutillo
Strauss
NEW MEXICO
EL PASO
MEXICO
DONA ANA CO.
OTERO CO.
21S
22S
23S
24S
25S
26S
27S
28S
29S
MESILLA VALLEY
NEW MEXICO
TEXAS

TABLE 90.—*Monthly temperatures and precipitation, United States Weather Bureau stations at El Paso, State College, and Elephant Butte Dam, 1936*

Month	El Paso				State College				Elephant Butte Dam			
	Temperature (°F.)			Precipitation (inches)	Temperature (°F.)			Precipitation (inches)	Temperature (°F.)			Precipitation (inches)
	Mean maximum	Mean minimum	Mean		Mean maximum	Mean minimum	Mean		Mean maximum	Mean minimum	Mean	
January	[illegible]	33.6	45.5	0.57	54.7	24.9	39.8	0.98	54.1	28.2	41.2	[illegible]
February	62.7	39.8	51.2	.06	60.7	31.5	46.1	.29	61.2	34.1	47.6	.12
March	70.0	45.9	58.0	T	69.2	35.3	52.2	.13	68.8	39.9	54.4	0
April	78.8	52.7	65.8	.11	77.6	[illegible]	60.2	.07	76.0	47.9	62.0	.05
May	86.5	61.8	74.2	.56	85.5	54.3	69.9	.70	83.7	56.9	70.3	.94
June	[illegible]	69.5	82.4	.34	94.9	[illegible]	77.1	.14	93.4	[illegible]	79.1	.29
July	94.1	71.2	82.6	.68	92.7	65.9	79.3	1.53	91.3	67.0	79.2	1.54
August	91.9	69.6	80.8	1.94	91.2	63.2	77.2	1.35	86.6	66.8	76.7	1.09
September	[illegible]	63.0	73.7	[illegible]	82.3	58.0	70.2	2.12	79.8	59.7	69.8	1.59
October	75.2	51.5	63.4	.32	74.5	42.6	58.6	.40	71.6	48.4	60.0	.26
November	61.4	39.8	50.6	1.32	61.2	32.2	[illegible]	1.02	58.3	35.8	47.0	.55
December	57.9	35.7	46.8	.51	56.9	27.9	42.4	.77	56.2	30.2	43.2	.01
Annual	76.3	52.8	64.6	9.93	75.1	44.8	60.0	9.50	73.4	48.3	60.9	6.93

studies would be concentrated in the Mesilla Valley since this Valley was representative of the entire Lower Valley and the time available for the studies was limited.

Experiment stations were established at State College and Mesilla Dam by the Bureau of Agricultural Engineering in cooperation with the agricultural experiment station of the New Mexico College of Agriculture and Mechanic Arts. Soil moisture and tank studies on use of water by alfalfa and cotton were made at State College, and experiments on evaporation and transpiration by native vegetation growing in wet areas at Mesilla Dam. Details of these experiments are described in later pages.

Rain gages were installed by the Bureau in cooperation with the Bureau of Reclamation at Leasburg Dam, Mesilla Dam, La Union, and Berino. The precipitation records for May to December 1936 are shown in table 91.

TABLE 91.—*Precipitation recorded at Leasburg Dam, Mesilla Dam, La Union, and Berino, in Mesilla Valley, N. Mex., 1936*

Month	Precipitation in inches			
	Leasburg Dam	Mesilla Dam	La Union	Berino
May		0.07		..
June	0.35	.41		
July	.68	1.09	1.07	1.39
August	.78	.84	2.03	2.25
September	2.17	1.72	2.56	2.60
October	.41	.35	.31	.15
November	1.21	.91	1.27	.85
December	.41		.67	..

Mesilla Valley extends as a fairly flat, long, narrow strip along the Rio Grande from Leasburg diversion dam in New Mexico to a few miles above El Paso, Tex. Its total length is about 55 miles. The maximum width of the Valley is about 5 miles, the average being in the neighborhood of 2½ miles. Figure 89 shows the location of the Valley.

As noted hereinbefore, Mesilla Valley experience in consumptive-use estimates has been used by engineers as a basis for estimating consumptive use in Middle Valley. The following estimates of past consumptive use in Mesilla Valley, for the years 1919 to 1935, inclusive, have been made by the Bureau of Agricultural Engineering.[9]

Consumptive Use in Mesilla Valley Prior to 1936

The methods outlined hereinbefore have been used in estimating the past consumptive use of water in Mesilla Valley. (See p. 345.) The sources of information for the estimates are stated in the following paragraphs relative to each of the methods used.

Inflow-outflow method.[10]—Conditions in Mesilla Valley are especially favorable for estimating consumptive use of water by the inflow-outflow method. The Bureau of Reclamation records, experiments of the Bureau of Agricultural Engineering and New Mexico Agricultural Experiment Station on use of water by agricultural crops, and the United States and Mexico Boundary Commission water measurement records all contribute to the reliability of consumptive-use estimates. Moreover, the Valley is a basin from which the subsurface outflow was long since found to be negligible. Tributary surface inflow is certainly less than in Middle Valley and in San Luis Valley. There is less certainty relating to subsurface tributary inflow, but this is considered relatively small. From 1919 to 1935 the irrigated area in Mesilla Valley ranged from 47,314 acres to 77,061 acres, and the total Valley area was reported by the Bureau of Reclamation as about 109,000 acres.[11]

[9] Prof. Albert S. Curry, collaborator, has assisted liberally in the interpretation of New Mexico Agricultural Experiment Station data, and in constructive criticism of the other studies. Dean W. Bloodgood, associate irrigation engineer, Bureau of Agricultural Engineering, whose writings on Mesilla Valley irrigation and drainage problems have been helpful, has also given valuable suggestions.

[10] The data used for the inflow-outflow method were supplied largely by L. R [illegible]

[11] [illegible]

Inflow.—The inflow measurements of the Rio Grande at Leasburg into Mesilla Valley have been made each year from 1919 to 1935, inclusive. Results of these measurements were supplied by the Bureau of Reclamation office at El Paso. (Pl. 20.)

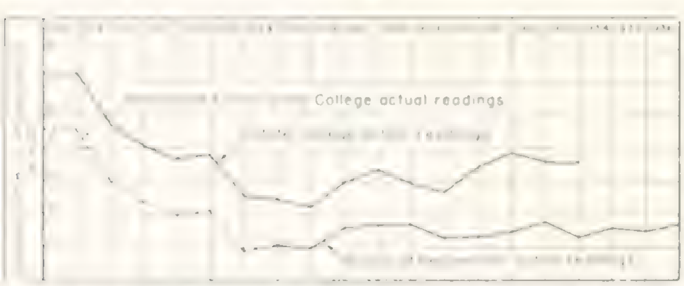
Records of arroyo inflow between Leasburg Dam and El Paso are estimates. However, in view of the fact that the annual water contribution from the arroyos is relatively very small (averaging probably not more than one percent of the annual consumptive use of the Valley), it is believed that the estimates are accurate enough to be considered here. The quantity (I) used in the computations is the sum of the river inflow at Leasburg and the arroyo inflow. (See p. 347.)

Precipitation.—The number of acre-feet of precipitation (P) contributed to the Valley water supply is based on precipitation measurements at State College, and on the Valley area (as reported by the Bureau of Reclamation), of 109,000 acres.

Outflow.—The outflow measurements have been made at El Paso (Courchesne) during all the years included in this study. They are considered reliable and probably the most accurate of all the measurements here dealt with. (Pl. 20.)

Ground-water Storage.—The amounts of changes in ground-water storage (G_s–G_e) are estimated from data supplied by the Bureau of Reclamation, the Bureau of Agricultural Engineering, and by the State Agricultural College. The Bureau of Reclamation records include the years 1925 to 1935, during which time depths to ground water were observed in 55 to 88 wells.

The Bureau of Reclamation wells are probably more nearly representative of the Valley as a whole than the State College wells, which were at first confined to 33 across the center of the Valley. However, the State College [12] well-depth records cover the years 1918 to 1924, and have been used as a basis for extending the Bureau of Reclamation records from 1924 back to 1918. The average depths for January of each year 1925 to 1934 are plotted on figure 90, by which the estimated



[illegible]

[12] [illegible]

depths of the Bureau of Reclamation wells are extended from 1924 back to 1918. The average difference in depth of water in the two sets of wells, for the years 1925 to 1934, has been added to the average depths of the State College wells for each year, 1918 to 1924, to get the probable average depths of water in the Bureau of Reclamation wells.

For estimates of difference in ground-water storage it was assumed that the specific yield was 15 percent of the total volume of soil (see p. 347).

Results by Inflow-outflow Method.—The Valley consumptive use (K) determined by use of equation 4 for the 17-year period, 1919–35, is given in column 6 of table 92. The irrigated area (A_t) is shown in column 7. It will be noted that the average for K for the 17-year period is 297,756 acre-feet, and the average K/A_t is 4.52 acre-feet per acre of irrigated land. This quantity includes all the precipitation (P) which, for the Valley area (A) of 109,000 acres, amounts to 1.18 acre-feet per acre of irrigated land per year, and therefore is not comparable with the estimates of other engineers for the quantity $\left(\frac{I-R}{A_t}\right)$ hereinbefore reviewed.

[illegible] 92.—Consumptive use of water in Mesilla Valley, N. Mex. and Tex., for 17-year period 1919 to 1935, based on inflow-outflow method [1]

Year	I Acre-feet	P	R Acre-feet	(G_s-G_e)	K Acre-feet	A_t	K/A_t	[illegible] acre
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
[illegible]	[illegible]	[illegible]	511,627	[illegible]	[illegible]	[illegible]	[illegible]	2.38
[illegible]	[illegible]	[illegible]	709,778	+10,955	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	+6,050	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	780,029	−1,962	[illegible]	[illegible]	5.52	2.46
[illegible]	924,197	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.43
[illegible]	992,123	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.77	[illegible]
1925	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.40	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.53
[illegible]	[illegible]	[illegible]	619,563	[illegible]	[illegible]	[illegible]	[illegible]	3.16
[illegible]	[illegible]	[illegible]	623,637	−327	576,[illegible]	[illegible]	4.95	3.45
[illegible]	768,935	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	790,538	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.12
[illegible]	[illegible]	[illegible]	567,240	[illegible]	[illegible]	[illegible]	4.22	2.97
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.41
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Average	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[1] [illegible]

The quantity (K) of column 6, table 92, consists of stream-flow depletion $(I-R)$, plus precipitation (P), plus draft on ground water (G_s-G_e). Comparisons of the averages show that the stream-flow depletion constitutes 73 percent of the consumptive use; precipitation, 26 percent; and draft on ground-water 1 percent. In terms of acre-feet per acre of irrigated land the averages for the 17-year period are as follows:

Stream-flow depletion $(I-R)/A_t$ equals	3.30
Precipitation P/A_t equals	1.18
Draft on ground water $(G_s-G_e)/A_t$ equals	0.04
	4.52

The stream-flow depletion of 3.30 acre-feet per acre of irrigated land is comparable with most of the estimates heretofore made by engineers and designated "consumptive use."

Stream-flow depletion is the most important item of the consumptive use. Irrigators are directly concerned with the net depletion of streams because of the use of water in irrigation. Moreover, it constitutes the largest of the three items included in consumptive use, being nearly three-fourths of it as an average for a 17-year period in Mesilla Valley. Precipitation on the valley floor tends to decrease the stream-flow depletion, but since precipitation cannot be controlled, the stream-flow depletion and its relation to irrigation areas and irrigation practices are of major practical importance.

The precipitation item (P/A_t) of 1.18 acre-feet per acre of irrigated land may be misleading because of the fact that it includes precipitation on the entire valley floor, only six-tenths of which, as an average, was used on cropped land. The consensus of opinion of authorities in Mesilla Valley seems to be that much of the precipiation which falls on the cropped lands of the valley is of but little, if any, direct benefit to crops.

In order to present amounts that are more nearly comparable with the estimates of engineers previously reported, table 93 was prepared. The quantity $(K-P)$, column 2, is stream-flow depletion plus difference in ground-water storage, as may be seen readily by subtracting the quantity (P) from both sides of equation (4). Then

$$(K-P)=(I-R)+(G_s-G_e).$$

For convenience, the quantity at the left of the equality sign in the foregoing equation is written on columns 2 and 4 of table 93, instead of its longer equivalent on the right.

Column 4 shows the average of the quantity $\left(\frac{K-P}{A}\right)$ for the 17-year period to be 3.36 acre-feet per irrigated acre. The average of 3.36 is almost identical with Hosea's 1929 Mesilla Valley 5-year estimate for the stream-flow depletion per acre irrigated $\left(\frac{I-R}{A_t}\right)$ for the years 1924 to 1928, namely, 3.42,[13] and with Debler's (1932) 4-year estimate of 3.40 acre-feet per irrigated acre for the years 1926 to 1929.

TABLE 93.—*Stream-flow depletion in Mesilla Valley, N. Mex. and Tex., for 17-year period 1919 to 1935, based on inflow-outflow method* [1]

Year	$K-P$ Acre-feet	A_t Acres	$\frac{K-P}{A_t}$ Acre-feet per acre	Proportion of average,[2] percent	$I-R$ Acre-feet	$\frac{I-R}{A_t}$ Acre-feet per acre
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1919	185,847	47,314	3.93	117.0	160,504	[illegible]
1920	103,890	48,327	2.15	64.0	92,935	[illegible]
1921	133,261	[illegible]	2.59	77.1	127,211	[illegible]
1922	217,733	48,620	4.48	133.3	219,695	[illegible]
1923 [3]	279,719	53,812	5.20	154.8	259,608	[illegible]
1924 [3]	189,918	61,966	3.06	91.1	193,352	[illegible]
1925	225,722	67,357	3.35	99.7	223,760	[illegible]
1926	254,463	76,244	3.34	[illegible]	266,071	[illegible]
1927	258,829	73,314	3.53	105.1	[illegible]	[illegible]
1928	291,368	76,057	3.83	114.0	291,695	[illegible]
1929	222,896	76,772	2.90	86.3	216,193	[illegible]
1930	258,374	76,373	3.38	100.6	258,538	[illegible]
1931	219,921	76,722	2.87	85.4	222,700	[illegible]
1932	243,229	76,709	3.17	94.4	248,788	[illegible]
1933	222,995	77,061	2.89	86.0	214,820	2.79
1934	254,845	68,605	3.71	110.4	259,750	3.79
1935	174,715	62,175	2.81	83.6	173,080	[illegible]
Average	219,866	65,814	3.36	100.0	217,019	3.30

[1] As determined by Bureau of Agricultural Engineering (see table 92) shows in column 2 stream-flow depletion plus difference in ground-water storage $(K-P)$ in acre-feet, and in column 4 in acre-feet per irrigated acre $\left(\frac{K-P}{A_t}\right)$ together with percentage of each year's results of 17-year average in column 5 and stream-flow depletion $(I-R)$ in acre-feet, and in acre-feet per acre of irrigated land $\left(\frac{I-R}{A_t}\right)$.

[2] Percent represented by corresponding yearly figures in column 4 relative to the average of column 4.

[3] Results based on Bureau of Reclamation records. See footnote 2, table 92.

The percentage of the quantity $\left(\frac{K-P}{A_t}\right)$ for each year, referred to the 17-year average, is given in column 5. Briefly summarized, the column 5 data show that during 6 years out of the 17, or 35 percent of the time, the consumptive use less precipitation was within 10 percent of the average for the period. During 13 years, or 76 percent of the time, the departure from the average did not exceed 20 percent, plus or minus; and during 14 of the 17 years the departure did not exceed 30 percent of the 17-year average. In 1 year, 1923, the consumptive use less precipitation exceeded the average by 55 percent.

Column 6 of table 93 shows the stream-flow depletion each year in acre-feet, and the average for the 17-year period. The average (217,019) plus the average change in ground water shown in column 5 of table 92 (2,847), is equal to the average consumptive use less precipitation shown in column 2 of table 93; namely, 219,866 acre-feet. The stream-flow depletion in acre-feet per acre of irrigated land, shown in column 7, indicates an average of 3.30 for the 17-year period. This average is only 0.06 acre-foot per acre less than the average of consumptive use less rainfall, shown in Column 4. The average stream-flow depletion $\left(\frac{I-R}{A}\right)$ for the 17-

[13] Hosea, [illegible]

[illegible] acres is 1.99 acre-feet per acre.

[illegible]. The [illegible] of the products of the areas of each crop (or group of crops) in acres, times the consumptive use for each crop, gives the consumptive use on all cropped land by [illegible] method.

[illegible] for different groups of crops in Mesilla Valley are given in table 94. The detailed Bureau of Reclamation crop surveys of agricultural lands are classified by New Mexico State College authorities in eight groups: alfalfa, cotton, forage crops, fruits, grains, pasture, vegetables, and miscellaneous. Column 2 of the table shows that there has been a decrease in the area devoted to alfalfa since 1923. The cotton area has increased greatly. Column 10 of the table shows the total cropped area each year.

Table 95 shows the classification of Mesilla Valley land areas into cropped area (A_c), native vegetation (A_n), water surface (A_w), bare land (A_t) and fallow land (A_f). Column 2 shows the growth in cropped area. There are no long-time records of Mesilla Valley areas in native vegetation. Column 3 of table 95 shows the native vegetation areas from 1919 to 1935 as determined by subtracting from the area of the Valley floor, 109,000 acres, the sum of the cropped acreage (A_c), the water surface acreage (A_w), the bare land surface area (A_t), and the fallow area (A_f). The general trend in area of native vegetation from 1919 to 1933 was downward, and the increase from 1933 to 1935 is apparently attributable to an assumed reversion of fallow land to native vegetation. It is estimated that about one-third of the native vegetation area was trees and two-thirds brush and grass.

[illegible] considerable experimental work has been done by the [illegible] in cooperation with the Bureau of Agricultural Engineering, with a view to finding the irrigation requirements and the consumptive use of alfalfa, cotton, grains, and some vegetables. Results of this experimental work have been accumulated for many years, and many [illegible] unpublished data have been analyzed.

It is believed that the consumptive use for cotton, [illegible] study, may be determined for like conditions with a fair degree of accuracy on the basis of the experimental data. A study of the relation of the yield of cotton [illegible]

[illegible] method B, by years, 1919–35

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Grains	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	(4)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	(10)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	44,280
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	45,861
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,431	0	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	14,4[illegible]	[illegible]	984	4,634	4,478	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	547	2,183	3,549	[illegible]	0	[illegible]
[illegible]	[illegible]	41,488	[illegible]	[illegible]	[illegible]	1,703	2,581	0	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3,418	902	3,768	2,502	69,724
[illegible]	[illegible]	[illegible]	1,227	[illegible]	6,455	1,310	3,426	0	71,261
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,331	2,740	0	75,162
[illegible]	[illegible]	[illegible]	1,048	[illegible]	1,444	1,012	2,439	[illegible]	[illegible]
[illegible]	[illegible]	53,619	[illegible]	548	[illegible]	[illegible]	3,103	0	[illegible]
[illegible]	[illegible]	47,106	1,760	549	[illegible]	[illegible]	2,826	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7,818	[illegible]	4,212	[illegible]	[illegible]
[illegible]	[illegible]	42,643	4,284	311	6,075	[illegible]	3,532	4,48[illegible]	[illegible]
[illegible]	12,767	35,356	4,626	[illegible]	[illegible]	1,565	[illegible]	413	[illegible]
[illegible]	[illegible]	33,185	[illegible]	[illegible]	4,497	[illegible]	3,073	700	58,667
[illegible]	14,9[illegible]	32,497	2,482	[illegible]	6,751	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 95.—*Mesilla Valley land classification in acres, used in estimating consumptive use by method B, by years, 1919–35*

Year	[illegible]	[illegible]	[illegible]	Bare	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	A_f	[illegible]
[illegible]	[illegible]	(3)	[illegible]	[illegible]	(6)	[illegible]
1919	[illegible]	[illegible]	7,000	[illegible]	[illegible]	[illegible]
1920	[illegible]	49,477	7,000	4,196	2,40[illegible]	109,000
[illegible]	[illegible]	46,397	7,000	4,196	[illegible]	[illegible]
1922	45,[illegible]	49,184	7,000	[illegible]	3,361	109,000
1923	49,[illegible]	[illegible]	4,004	4,196	[illegible]	109,000
1924	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	109,000
1925	63,[illegible]	[illegible]	[illegible]	4,196	[illegible]	109,000
1926	69,[illegible]	24,5[illegible]	[illegible]	4,196	6,520	109,000
[illegible]	71,[illegible]	[illegible]	[illegible]	4,196	2,053	109,000
1928	75,[illegible]	[illegible]	[illegible]	4,196	[illegible]	109,000
1929	[illegible]	24,028	4,004	4,196	[illegible]	109,000
1930	75,[illegible]	[illegible]	4,004	4,196	628	109,000
1931	7[illegible]	21,078	4,004	4,196	1,406	109,000
1932	[illegible]	21,091	4,004	4,196	[illegible]	109,000
1933	[illegible]	23,739	[illegible]	4,196	1,229	[illegible]
[illegible]	[illegible]	[illegible]	4,004	[illegible]	12,976	109,000
1935	58,[illegible]	27,875	4,004	[illegible]	14,258	109,000

use up to 2 acre-feet per acre, and that beyond a use of 3 acre-feet per acre, the increase in yield was so small as to be negligible. On the basis of these data an estimated unit consumptive use of 2.5 is probably near the truth. It is believed that the error of the average consumptive use is not more than 10 percent.

Estimates of the consumptive use of alfalfa are subject to a larger error. An analysis of the relation of alfalfa yield to the amount of irrigation water used, based on many years of experimental work in Mesilla Valley as reported by the New Mexico Agricultural Experiment Station and Bureau of Agricultural Engineering (7), seems to indicate that alfalfa yield was not increased much, if at all, with increase in amounts of irrigation water beyond 4 acre-feet per acre. All the data published about the more recent work on the consumptive use of alfalfa, as summarized by Prof. A. S. Curry, [illegible]

5 acre-feet (60 acre-inches) per acre. The chances are probably equal that the consumptive use of alfalfa may vary at least plus or minus 20 percent from the average consumptive use based on the experimental work for like conditions.

There are but few experimental data in New Mexico to form the basis of estimating the unit consumptive use of crops other than alfalfa, cotton, fruits, pasture and vegetables.

Estimates of Valley Consumptive Use.—The crop areas shown in table 94, which are based on Bureau of Reclamation records, are reproduced in table 96 with minor modifications to correct for duplications of some crops. It is important to note that the sum of the 17-year average areas for alfalfa and cotton (47,401 acres) is over 75 percent of the average cropped area of 62,850 acres, and that cotton alone represents more than 50 percent of the cropped area on the average. During the 5-year period 1928 to 1932 more than two-thirds of the cropped area was in cotton.

The unit consumptive use for alfalfa, cotton, and each of the other six groups of crops as used herein, is shown in line 3 of table 96. The experimental data described above have been used as a basis for the unit use estimates. The estimates for forage, fruits, pasture and miscellaneous crops, shown in columns 5, 6, 8, and 10 respectively of table 96, are based on experimental work in other States as well as New Mexico. They may, therefore, be less reliable than the estimates for alfalfa, cotton and grains.

Based on a net annual use, by alfalfa, of 4 acre-feet per acre and by cotton of 2.5 (the amounts used in table 96) these two crops (as an average for the 17-year period) used nearly 82 percent, or more than four-fifths of the consumptive use by all crops. It is, therefore, evident that the selection of unit consumptive use values for these two crops is of major importance. Cotton alone used an average of more than 81,000 acre-feet, which is 47 percent of the total amount used by all crops.

An error of 15 percent in the consumptive use by cotton would make an error of 7 percent in the use by all crops; whereas, an error of 100 percent in the unit value for pasture or vegetables would make an error of only 4 percent in the use by all crops. The use by miscellaneous crops is negligible.

Column 11 of table 96 shows the amounts of water consumed on cropped land. The average for the 17-year period is approximately 173,000 acre-feet; in round numbers the maximum is 205,000, and the minimum is 126,000. The maximum is 18 percent higher than the average, and the minimum is 27 percent lower.

Table 96.—*Amounts of water in acre-feet consumed by Mesilla Valley crops as estimated by multiplying assumed unit consumptive use by the acreage of each crop each year from 1919 to 1935, inclusive, by integration method B*

Year	Item	Crop and unit use (c)								Total crop [illegible]
		Alfalfa	Cotton	Forage	Fruits	Grains	Pasture	Vegetables	Miscellaneous	
		4.0	2.5	3.0	2.0	1.5	3.0	2.0	2.00	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
[illegible]	[illegible]	19,100	24	2,616	700	15,156	3,845	2,839	0	
	(ca)	76,400	60	7,848	1,400	22,790	11,535	5,678	0	125,711
[illegible]	(a)	16,795	6,682	1,534	[illegible]	13,422	3,270	3,390	0	
	[illegible]	67,180	16,705	4,602	1,536	20,200	9,810	6,780	0	126,813
[illegible]	(a)	18,923	[illegible]	3,192	478	16,218	[illegible]	1,431	0	
	(ca)	75,692	1,298	9,576	956	24,300	16,719	2,862	0	131,403
[illegible]	(a)	20,270	2,731	1,934	708	11,617	3,682	4,033	[illegible]	
	(ca)	81,080	6,827	5,802	1,416	17,400	11,046	8,066	568	132,205
[illegible]	(a)	[illegible]	14,452	4,453	984	4,634	[illegible]	219	0	
	(ca)	82,636	36,130	13,359	1,968	6,950	13,434	438	0	154,915
[illegible]	(a)	15,344	29,049	2,555	547	[illegible]	[illegible]	2,545	0	
	(ca)	61,376	72,623	7,665	1,094	[illegible]	10,647	5,090	0	161,769
[illegible]	[illegible]	[illegible]	41,488	1,529	801	2,330	1,703	[illegible]	0	
	(ca)	52,272	103,720	4,587	1,602	3,495	5,109	5,162	0	175,947
[illegible]	[illegible]	[illegible]	43,860	910	701	3,118	902	3,768	[illegible]	
	(ca)	54,652	109,650	2,730	1,402	5,127	2,706	7,536	5,004	188,807
[illegible]	[illegible]	14,974	43,430	1,227	439	6,455	1,310	3,426	0	
	(ca)	59,896	108,600	3,681	878	9,682	3,930	6,852	0	193,519
[illegible]	[illegible]	10,422	57,220	925	[illegible]	2,326	1,331	2,740	0	
	(ca)	[illegible]	143,000	2,775	396	3,489	3,993	5,180	0	200,821
[illegible]	[illegible]	[illegible]	58,815	1,048	650	1,444	1,012	2,439		
	(ca)	42,668	[illegible]	3,144	1,300	2,166	3,036	4,878	0	203,992
[illegible]	[illegible]	12,927	53,619	1,584	348	3,377	787	3,103	0	
	[illegible]	51,708	134,000	4,752	[illegible]	5,065	2,361	6,206	0	204,788
[illegible]	[illegible]	[illegible]	47,106	1,760	549	7,493	869	2,826	0	
	[illegible]	58,860	117,500	5,280	1,098	11,239	2,607	5,652	[illegible]	202,236
1932	[illegible]	14,783	42,271	3,505	389	7,818	1,966	4,212	0	
	[illegible]	59,132	105,700	10,515	778	11,727	5,898	8,424	[illegible]	202,174
1933	(a)	12,807	42,643	4,284	311	6,075	1,695	3,532	4,485	
	[illegible]	51,228	106,560	12,852	622	9,112	5,085	7,064	8,970	201,433
[illegible]	[illegible]	[illegible]	35,356	4,626	[illegible]	6,305	1,565	3,129	413	
	[illegible]	51,068	88,400	13,878	1,372	9,457	4,695	6,258	826	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	4,505	[illegible]	[illegible]	719	3,073	700	
	[illegible]	45,968	83,000	13,515	[illegible]	[illegible]	2,157	6,146	1,400	[illegible]
[illegible]	[illegible]	[illegible]	32,497	2,482	[illegible]	6,751	2,250	2,899	493	
[illegible]	[illegible]	[illegible]	81,243	7,446	[illegible]	10,130	6,750	[illegible]	989	[illegible]

Note: [illegible] in acre-feet per acre by area (a) [illegible] consumptive use [illegible] acre-feet.

Because there can be no precise selection of unit consumptive use amounts applicable to a large valley such as the Mesilla Valley, two additional sets of assumed values have been selected and crop consumptive use determined each year for the 10-year period ending 1933, as shown in tables 97 and 98. The assumed unit consumptive use for alfalfa in table 97 is 3 acre-feet per acre, and in table 98 it is 5 feet, thus being three-fourths and five-fourths of the amount assumed in table 96. For cotton, the amount in table 97 is 2.0 acre-feet per acre, and in table 98 it is 3 feet, being four-fifths and six-fifths, respectively, of the amount used in table 96. Differences for other crops are of minor importance and can be compared in the tables.

In order to make the results of the analysis in tables 97 and 98 strictly comparable with those of table 96, the same 10-year period must be used. The average crop consumptive use for the Valley lands on the basis of the 10-year period 1924–33 and the unit consumptive use values in table 96 is 193,548 acre-feet. This is 25 percent higher than the average of 154,740 in table 97 and 17 percent lower than the average of 233,090 in table 98.

It is probable that the inflow-outflow method is more reliable for Mesilla Valley than the integration method.

[illegible] *based on low estimates of unit consumptive use as shown in columns 3 to 10, inclusive, by integration method B*

Year	[illegible]	[illegible]	Cotton	[illegible]	Fruits	Grains	Pasture	Vegetables	Miscellaneous	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.0	
(1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	(10)	[illegible]
[illegible]	[illegible]	15,341	29,049	[illegible]	[illegible]	2,183	[illegible]	[illegible]	0	
	[illegible]	46,032	58,098	7,665	820	3,274	8,860	[illegible]	0	128,567
[illegible]	(a)	13,068	41,488	1,529	[illegible]	2,330	[illegible]	2,581	[illegible]	
	(ca)	39,204	82,976	4,587	1,201	3,495	4,257	3,871	0	139,591
[illegible]	(a)	13,663	43,860	[illegible]	701	3,418	[illegible]	3,768	2,502	
	(ca)	40,989	87,720	2,730	1,051	[illegible]	2,250	5,652	5,004	150,523
[illegible]	[illegible]	14,974	43,430	1,227	[illegible]	[illegible]	1,310	3,426	0	
	(ca)	44,922	86,860	3,681	658	9,682	3,280	5,139	[illegible]	154,222
[illegible]	(a)	10,422	57,220	925	[illegible]	2,326	1,331	2,740	[illegible]	
	(ca)	[illegible]	114,440	2,775	297	3,489	3,330	4,110	[illegible]	159,707
[illegible]	(a)	10,667	58,815	1,048	650	1,444	1,012	[illegible]	[illegible]	
	(ca)	32,001	[illegible]	3,144	975	[illegible]	2,530	[illegible]	[illegible]	162,104
[illegible]	(a)	12,927	53,619	[illegible]	348	3,377	787	3,103	[illegible]	
	(ca)	[illegible]	107,238	1,752	[illegible]	[illegible]	1,967	4,655	0	162,980
[illegible]	[illegible]	14,715	[illegible]	[illegible]	[illegible]	7,493	869	[illegible]	0	
	[illegible]	[illegible]	94,212	[illegible]	823	11,239	2,175	4,239	0	162,113
[illegible]	[illegible]	14,783	42,271	3,505	589	7,818	1,966	4,212	0	
	[illegible]	44,349	84,542	10,515	583	11,727	4,915	6,318	[illegible]	162,949
[illegible]	[illegible]	12,807	42,643	4,284	311	6,075	1,695	[illegible]	[illegible]	
	[illegible]	38,421	85,286	12,852	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	164,645
[illegible]	[illegible]	13,337	[illegible]	1,933	[illegible]	4,292	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	91,900	[illegible]	740	[illegible]	[illegible]	[illegible]	1,398	154,740

NOTE.—ca= the product of unit consumptive use (c) in acre-feet per acre by area (a) in acres=consumptive use in acre-feet.

TABLE 98. *Amounts of water in acre-feet consumed by Mesilla Valley crops for the 10-year period 1924–33, based on high estimates of unit consumptive use as shown in columns 3 to 10, inclusive, by integration method B*

[illegible]	[illegible]	[illegible]	Cotton	[illegible]	[illegible]	Grains	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]	3.0	3.5	2.0	2.0	3.0	2.0	2.0	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	(6)	[illegible]	(8	[illegible]	[illegible]	(11)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	547	2,183	[illegible]	[illegible]	[illegible]	
	[illegible]	76,720	87,147	8,912	1,094	4,366	10,647	[illegible]	[illegible]	191,006
1925	(a)	13,068	41,488	1,529	801	2,330	1,703	2,581	[illegible]	
	[illegible]	65,340	124,464	5,352	1,602	4,660	5,109	5,162	[illegible]	[illegible]
1926	[illegible]	[illegible]	43,860	[illegible]	701	3,418	902	3,768	2,502	
	[illegible]	68,315	[illegible]	3,185	1,402	6,836	2,706	7,536	[illegible]	[illegible]
[illegible]	[illegible]	14,974	43,430	[illegible]	[illegible]	6,455	1,310	3,426	0	
	[illegible]	74,870	130,290	4,294	878	12,910	3,930	[illegible]	[illegible]	234,024
[illegible]	[illegible]	[illegible]	57,220	925	[illegible]	2,582	1,331	2,740	0	
	(ca)	[illegible]	171,660	3,237	[illegible]	5,164	3,993	[illegible]	[illegible]	242,040
[illegible]	[illegible]	[illegible]	58,815	[illegible]	[illegible]	[illegible]	1,012	2,439	0	
	[illegible]	53,335	[illegible]	3,668	1,300	2,888	3,036	4,878	[illegible]	[illegible]
[illegible]	[illegible]	12,927	53,619	[illegible]	348	3,377	787	[illegible]	0	
	(ca)	[illegible]	160,857	5,644	696	6,754	2,361	6,206	0	[illegible]
[illegible]	[illegible]	[illegible]	47,106	1,760	549	7,493	[illegible]	[illegible]	[illegible]	
	(ca)	73,575	141,318	6,160	1,098	14,986	2,607	[illegible]	0	245,396
[illegible]	[illegible]	14,783	[illegible]	[illegible]	589	7,818	1,966	4,212	0	
	[illegible]	73,915	[illegible]	12,267	778	15,636	5,898	8,424	[illegible]	243,731
1933	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

If this be true, the unit amounts for consumptive use given in tables 96 and 98 are closer to the true amounts for the Valley as a whole than those of table 97. This means that the estimates of 3 acre-feet per acre for alfalfa and 2 acre-feet per acre for cotton are too low; whereas, unit consumptive values for alfalfa from 4 to 5 acre-feet per acre and for cotton of 2.5 to 3.0 acre-feet per acre give results for the Valley consumptive use closer to those obtained by the inflow-outflow method.

Combined Consumptive Uses.—In table 99 the results of the integration method for agricultural crops, taken from table 96, are combined with estimated evaporation losses from fallow lands, use by native vegetation, and evaporation losses from bare lands and from water surfaces. The term "fallow" is applied to the land which is classed by the Bureau of Reclamation as irrigated but not cropped. The area is relatively small, and it is assumed that this land sustains an evaporation loss of 1 acre-foot per acre per year. Other assumed unit amounts in table 99 are trees, 3.5; brush and grass, 2.5, and bare land, a depth equal to the annual rainfall.

The water surface evaporation (E_w) is based on actual evaporation measured in a standard Weather Bureau evaporation pan at State College and taken as 0.7 of the amount for each year.

Column 8 shows the consumptive use (K) in acre-feet by the integration method for Mesilla Valley. There is relatively little variation in the amounts of column 8, the maximum being only 6 percent higher than the average, and the minimum but 9 percent lower than the average.

The actual variation in the consumptive use from year to year is perhaps greater than the data of column 8 indicate because there is variability in the unit amounts consumed per acre by the different crops, whereas column 2 of table 99 (the major single item in column 8) is based on the assumption that the consumptive use of each crop does not vary from year to year.

It is of interest to note that the average by integration method B (table 99) for the 17-year period (297,291 acre-feet), is almost the same as the average for the same period as found by inflow-outflow method A, which is 297,756, as shown in table 92.

On the basis of the estimated amounts of consumptive use for various types of land as shown in table 99 (made by method B), it is apparent that 93,587 acre-feet of water estimated to be the average amount consumed by the native vegetation from 1919 to 1935 is approximately 31 percent of the average total consumptive use (K) of 297,291 acre-feet.

The average use by all other classes of land as shown in table 99 (method B) is 203,704 acre-feet. If this amount is subtracted from the average consumptive

TABLE 99.—*Consumptive use of water in Mesilla Valley, N. Mex. and Tex., as determined by integration method B, 1919 to 1935, inclusive*

	Consumptive use of water, acre-feet						
Year	Cropped land	Fallow land	Native vegetation (K_n)		Water surface	Bare land	Total use
	K_c	K_f	Trees	Brush and grass	E_w		K
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1919	125,7[illegible]1	3,034	57,315	85,203	36,900	2,820	310,983
1920	126,813	2,466	56,284	84,925	37,400	2,862	310,750
1921	131,103	5,073	52,776	78,295	37,900	2,672	308,119
1922	132,26[illegible]	3,361	[illegible]5,948	82,998	39,300	1,955	315,767
1923	154,915	3,932	53,148	79,295	19,920	[illegible]	315,130
1924	161,769	6,194	44,170	65,530	19,750	[illegible]	[illegible]
1925	175,947	3,856	37,930	[illegible]	18,220	2,730	294,951
1926	188,867	6,520	27,933	41,437	17,880	5,020	287,597
1927	193,[illegible]	2,053	31,266	46,382	19,450	3,310	295,980
1928	200,821	89[illegible]	28,143	41,755	[illegible]	3,270	293,884
1929	20[illegible],992	[illegible]	27,332	[illegible]	18,140	[illegible]	293,929
1930	204,788	628	27,786	41,220	19,480	2,410	296,312
1931	202,236	1,406	27,388	40,632	19,260	4,630	295,552
1932	202,171	1,773	27,405	40,653	23,400	3,090	298,495
1933	201,4[illegible]	1,229	27,003	40,060	24,420	[illegible]	295,791
1934	175,9[illegible]	3,758	26,138	38,773	25,200	1,613	271,436
1935	159,924	3,508	31,707	47,040	24,070	[illegible]	270,679
Average	173,082	2,964	37,645	55,942	24,658	3,000	297,291
Percentage	58.2	1.0	12.7	18.8	8.3	1.0	100.0

use (K) of 297,756 acre-feet as determined by method A (see table 92), the average consumptive use of water by native vegetation is 94,052 acre-feet for the period 1919 to 1935.

Method C (based on Hedke).—A method of estimating consumptive use by means of a study of the heat units available to the crops of a particular valley has been suggested by Hedke (25) (26). This method assumes that there is a linear relation between the amount of water consumed and the quantity of available heat.[14] The assumed relation, in mathematical language is as follows:

$$U_v = K_h (Q_h)^{15}$$

Hedke found the magnitude of K_h to be 4.23×10^{-4} for the Cache La Poudre Valley, Colo. For the crops grown on the Rio Grande Project he found, in 1924, a total heat requirement of 6,800 day-degrees (26), and a corresponding total valley water consumption of 2.88 acre-feet "per cropped acre."

[14] The application of the direct relation between water consumption and available heat, proposed by Hedke, to a valley in which the agricultural practices are of a high standard, appears to necessitate the following assumptions: (1) That the heat consumed by a particular crop, during any day or other time period, is determined by the amount of heat available to the crop above the germinating or minimum growing temperature; (2) That under favorable agricultural practices, each crop consumes water in direct relation to the heat available as defined; (3) That the soils considered are abundantly supplied with moisture and plant-food so that the yield of a crop will be limited only by the amount of heat available; (4) That the influence of variations in wind velocity, relative humidity, and vapor pressure on consumptive use of water are relatively small as compared to the influence of available heat (25, p. 1366).

[15] The symbols used by the Committee of the American Society of Civil Engineers in this equation are taken from reference 25, p. 1396. The meaning of each symbol follows: U_v = valley consumptive use, Q_h = quantity of available heat in day-degrees, K_h = the Hedke coefficient. The subscript "h" is added to the K in Reference 25 to distinguish Hedke's coefficient from the consumptive use (K) used by Bureau of Agricultural Engineering.

[illegible] valley consumptive use in the Cache La Poudre Valley. For what he designated the "normal year", Hedke found the consumptive use to be 2.03 acre-feet per cropped acre.

The normal rainfall in Cache La Poudre Valley is 1.16 feet, according to Hedke. Of this normal amount he considered one-half "effective" and, therefore, a part of the consumptive use.

Relation to Mesilla Valley—It is perhaps impractical to use the Hedke constant K_h evaluated on the basis of the Cache La Poudre Valley studies, to estimate closely the Valley consumptive use in Mesilla Valley. Reasons for this statement are:

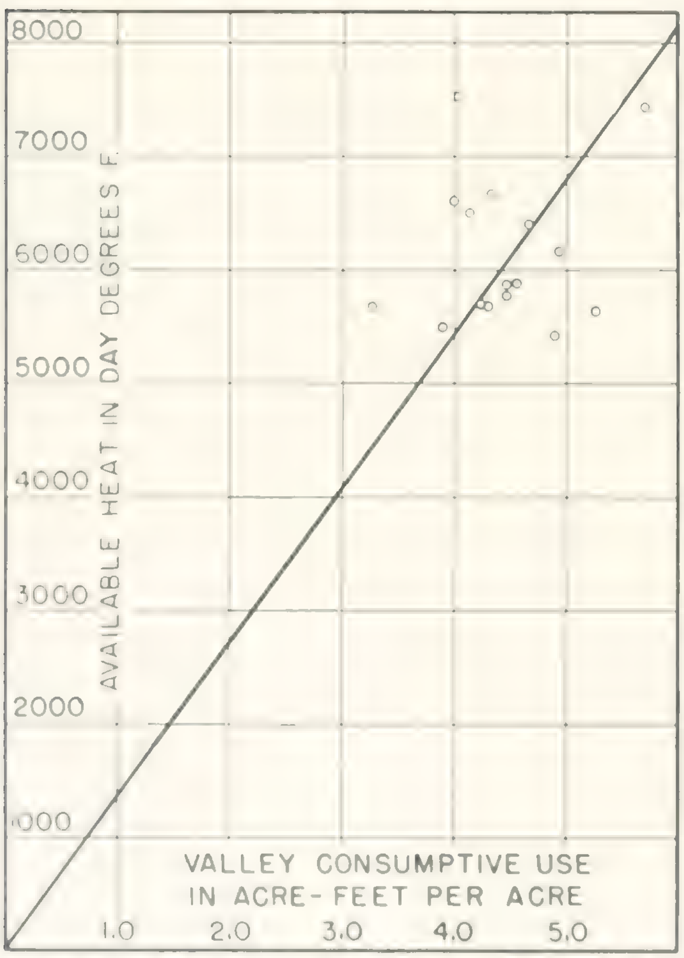
a. [illegible]
b. Probably 75 to 80 percent of the Cache La Poudre Valley land was cropped in 1916 and 1917; whereas only 60 percent of Mesilla Valley area was cropped from 1919–35.
c. The cropped area of 225,000 acres for Cache La Poudre Valley is probably too large.
d. Not all the Cache La Poudre Valley outflow was actually measured in 1917.
e. The Cache La Poudre Valley studies did not continue long enough to give results comparable to the direct measure- [illegible]

A direct application of the relation of available heat in Mesilla Valley to consumptive use of water during the period 1919 to 1935 has enabled the Bureau to evaluate new constants for the Hedke equation. The estimated minimum growing temperatures used for various crops were: Alfalfa, 33° F.; cotton, 48°; forage, 44°; fruits, 46°; grains, 44°; pasture, 33°; vegetables, 40°; miscellaneous, 38°.

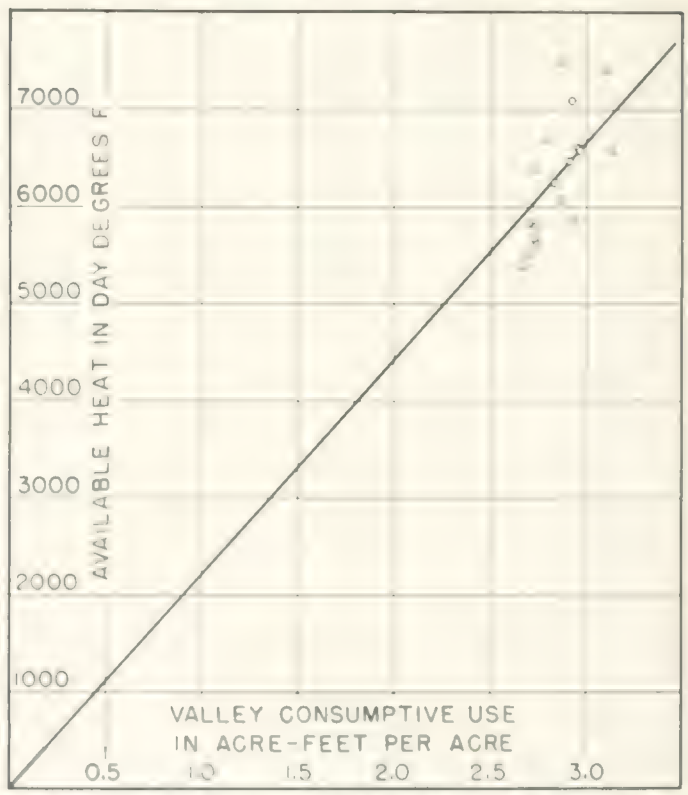
The average quantity of available heat (that is, Hedke's "thermal location") for the 17-year period, is 6,200 day-degrees. This is 9 percent lower than the quantity found by Hedke in 1924, but is based on much longer therefore and more reliable records of Mesilla Valley crop production.

In figure 91 the quantity of available heat Q_h is plotted against the Valley consumptive use in acre-feet per acre irrigated $\left(\frac{K}{A_i}\right)$ as determined by inflow-outflow method (table 92). The Hedke constant resulting from the straight line curve of figure 91 is 7.3×10^{-4}, or 0.00073.

In figure 92 the available day-degrees of heat each year are plotted aginst the crop consumptive use per acre of cropped land $\left(\frac{K_c}{A_c}\right)$ as determined by integration



[illegible]



[illegible]

method (tables 94 and 96). A straight line through the origin and the points thus plotted, gives a value of K_h equal to 1.4×10^{-4}, or 0.00014.

Application to Middle Rio Grande Valley.—For the Middle Valley Hedke found the available heat to be 6,200 day-degrees, the same amount found herein for the Mesilla Valley. The Bureau's analyses [16] for the Middle Valley are based on an average minimum growing temperature of 40°, assumed to be the average for all crops, and on mean monthly temperatures at Albuquerque, N. Mex. On these bases it is found that the average heat available is 5,600 day-degrees. With this quantity of available heat, and on the basis of Mesilla Valley consumptive-use studies during a 17-year period, as shown in figure 91, the Middle Valley consumptive use (based on method C) would be 4.1 acre-feet per irrigated acre $\left(\frac{K}{A_i}\right)$. Similarly using results shown in figure 92 the crop consumptive use per cropped acre $\left(\frac{K_c}{A_c}\right)$ would be 2.5. The latter value compares favorably with results obtained by method B in Middle Valley which range from 2.41 acre-feet per acre in the Cochiti division to 2.73 acre-feet per acre in the Belen division (tables 68 to 71).

Conclusion Regarding Methods

The inflow-outflow method is probably the most reliable method of estimating consumptive use in Mesilla Valley. However, if based upon careful estimates of unit consumptive use by the principal agricultural crops (now alfalfa and cotton) and native vegetation, and upon an accurate distribution of their acreages, it is likely that the integration method will produce satisfactory results.

[16] These analyses of Middle Valley are of a preliminary nature only.

Further and more comprehensive research into the relation of available heat to consumptive use of water must be carried out to make the Hedke method comparable in accuracy and reliability to the inflow-outflow and integration methods.

Consumptive Use in Mesilla Valley Area, 1936

The consumptive use of water in the Mesilla Valley area was determined by both the inflow-outflow method and the integration method, as follows:

Inflow-outflow method A.—The Mesilla Valley area was chosen for the 1936 study of consumptive use and stream-flow depletion because of the availability of reliable inflow and outflow records for many years, and for other reasons discussed on p. 379. The area as mapped by the Bureau of Agricultural Engineering in June 1936, has a total area of 110,418 acres and an irrigated area of 82,923 acres (table 101[17]).

The equation $K=(I+P)+(G_s-G_e)-R$ was used in computing Valley consumptive use (p. 347). By definition (p. 346) the items in this equation are for a period of 1 year. However, monthly values are used in the 1936 computations for the sake of greater accuracy and to show the seasonal variation.

Inflow.—The inflow (I) for Mesilla Valley area includes the Rio Grande inflow at Leasburg gaging station plus inflows of arroyos between Leasburg and Courchesne (El Paso). These measurements were made by the Bureau of Reclamation. The arroyo inflows are relatively small (table 100).

[17] This is the same section of the Lower Valley as that used in the 1919 to [illegible] studies, but the total area of the tract is taken as mapped by the Bureau of Agricultural Engineering in 1936, rather than 109,000 acres as previously reported by the Bureau of Reclamation. However, the difference in acreages is relatively so small that either can be used without changing the unit consumptive use figures more than a few hundredths. The 1936 figures are therefore comparable with those for previous years.

TABLE 100.—*Consumptive use of water in the Mesilla Valley area, New Mexico and Texas, 1936 based on inflow-outflow method* [1]

Period	Leasburg inflow	Arroyo inflow	I	P	R	G_s-G_e	$I-R$	K	$\frac{I-R}{A_i}$	$\frac{K}{A_i}$	$\frac{I-R}{A}$	$\frac{K}{A}$
	Acre-feet								Acre-feet per acre			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
January	3,800	0	3,800	7,180	8,600	+3,310	−4,800	5,690	−0.06	0.07	−0.04	0.05
February	13,540	0	13,540	1,660	10,700	+1,660	2,840	6,160	.03	.07	.03	.06
March	[illegible]	[illegible]	50,840	1,200	29,400	−3,310	21,440	19,330	.26	.23	.19	.18
April	93,550	[illegible]	93,550	[illegible]	50,800	−9,940	[illegible]	33,640	.52	.41	[illegible]	.30
May	89,850	8	89,858	4,050	62,500	−3,310	[illegible]	28,098	.33	.34	.25	.25
June	105,200	4	105,204	2,300	62,800	−1,660	42,404	43,044	.51	.52	.38	.39
July	[illegible]	[illegible]	123,299	9,850	76,500	−1,660	46,799	54,989	.56	.66	.42	.50
August	122,310	[illegible]	123,190	14,080	79,700	−3,310	43,490	54,260	.52	.65	.39	[illegible]
September	63,320	512	63,832	22,540	50,500	+4,970	13,332	40,842	.16	.49	.12	.37
October	12,170	0	12,170	2,940	17,800	+4,970	−5,630	2,280	−.07	.03	−.05	.02
November	9,020	0	9,020	10,120	12,500	+6,620	−3,480	13,260	−.04	.16	−.03	.12
December	7,000	0	7,000	5,430	12,000	+1,660	−5,000	2,090	−.06	.03	−.05	.02
Total	[illegible]	2,043	695,303	82,180	473,800	[illegible]	221,503	303,683	2.67	3.66	2.01	2.75

[1] As determined by Bureau of Agricultural Engineering from inflow (I); precipitation (P); outflow (R); difference in ground-water storage (G_s-G_e); stream-flow depletion ($I-R$); valley consumptive use (K); irrigated area (A_i) = 82,923 acres; total area (A) = 110,418 acres; stream-flow depletion per irrigated acre $\left(\frac{I-R}{A_i}\right)$ and per acre for entire area $\left(\frac{I-R}{A}\right)$ consumptive use per irrigated acre $\left(\frac{K}{A_i}\right)$ and per acre for entire area $\left(\frac{K}{A}\right)$. By definition these items are annual amounts [illegible] in tabulations to illustrate method of computing.

Precipitation.—The quantity (P) = the product of precipitation in feet times the area of the Valley (110,418 acres). Records for the entire year are only available for State College and El Paso as shown in table 90. These were used together with records for part of the year from the stations established by the Bureau of Agricultural Engineering late in May 1936 (table 91) at Leasburg Dam, Mesilla Dam, La Union and Berino.[18]

Outflow.—For the quantity (R) only the discharge of the Rio Grande at Courchesne (El Paso) gaging station need be considered. Records of these measurements were furnished by the International Boundary Commission (table 100).

Ground-Water Storage.—The amount of change in ground-water storage ($G_s - G_e$) is estimated from monthly well records furnished by the Bureau of Reclamation and an assumed specific yield of 15 percent (p. 347).

Results.—The results of the 1936 consumptive-use-of-water and stream-flow-depletion studies, together with the monthly values for the various items used in the computations, are shown in table 100.

The total Valley consumptive use (K) for the year 1936 is 303,683 acre-feet and the stream-flow depletion ($I-R$) 221,503 acre-feet. These amounts agree closely with the 17-year averages of 297,756 acre-feet consumptive use (K) and 217,019 acre-feet stream-flow depletion ($I-R$).

The consumptive use on an acreage basis is 3.66 acre-feet per irrigated acre $\left(\frac{K}{A_i}\right)$, and 2.75 acre-feet per acre for entire area $\left(\frac{K}{A}\right)$. The same values for the 17-year period shown in table 92 are 4.52 and 2.75 acre-feet per acre, respectively. The increase in area of irrigated land in 1936 over previous years accounts for the lower value of $\left(\frac{K}{A_i}\right)$ in 1936.

The stream-flow depletion is 2.67 acre-feet per acre irrigated $\left(\frac{I-R}{A_i}\right)$ and 2.01 acre-feet per acre for entire area $\left(\frac{I-R}{A}\right)$.

Integration Method B.—The acreages of the different types of land mapped in the Mesilla Valley area by the Bureau of Agricultural Engineering in 1936 are shown in column 2 of table 101. Two sets of unit consumptive use values for various types of land, estimated from previous and 1936 experiments in the Valley, are shown in columns 3 and 5 for the purpose of comparison.

The unit values shown in column 3 are probably more nearly representative of present use of water in the Valley than those in column 5. The average consumptive use of 2.75 acre-feet per acre for the entire valley is the same as the amount determined by the inflow-outflow method (table 100). By deducting the annual precipitation from the average consumptive use (2.75), the stream-flow depletion would appear as about 2 acre-feet per acre or approximately the same as that obtained by the inflow-outflow method (table 100). The average use for irrigated cropped land amounts to 2.79 acre-feet per acre (column 3, table 101), while the use by native vegetation averages 3.27 acre-feet per acre.

[18] [illegible]

[illegible] *New Mexico and Texas, as estimated by integration method,* [illegible]

[illegible]	[illegible]	Consumptive use[1]			
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
(1)	[illegible]	[illegible]	(4)	[illegible]	[illegible]
[illegible]					
[illegible]	17,077	4.1	[illegible]	4.0	[illegible]
[illegible]	54,513	[illegible]	[illegible]	2.5	[illegible]
[illegible]	216	2.5	[illegible]	[illegible]	497
[illegible]	11,117	[illegible]	24,457	2.0	[illegible]
[illegible]	[illegible]	[illegible]	231,295	2.74	227,321
[illegible]					
[illegible]	2,733	2.5	6,833	[illegible]	6,286
[illegible]	[illegible]	2.8	19,412	2.5	17,332
[illegible]	[illegible]	4.8	[illegible]	5.0	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Miscellaneous:					
Temporarily out of crop-[illegible]	[illegible]	1.0	[illegible]	[illegible]	[illegible]
[illegible]	1,523	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	4,081	4.5	[illegible]	4.5	[illegible]
Bare land, roads, etc.	3,124	.7	2,187	.7	[illegible]
Total (entire area)	[illegible]	[illegible]	[illegible]	[illegible]	300,550

[1] [illegible]

Soil-Moisture Studies

Agricultural Crops, 1936

In recent years, by far the most extensive crop grown in the Lower Valley has been cotton. Alfalfa has occupied the next largest area. These two crops were chosen, therefore, for the studies of consumptive use as measured by soil-moisture determinations on selected plots.

Soil-moisture studies, centered at State College, were carried on in cooperation with the New Mexico Agricultural Experiment Station. Field plots for cotton experiments were selected at three locations: Agronomy farm, field EC, and field 9W. Suitable sites for alfalfa studies were limited, so the only plot selected was on the horticultural farm. Soil-moisture determinations were made in the college laboratory by standard methods, by the Bureau of Agricultural Engineering.

Soil samples were taken from each plot by means of a Veihmeyer-type soil tube, before and after each irriga-

tion. From each hole seven samples were taken so as to give one sample from the surface to a depth of 6 inches, the next for the depth 6 to 12 inches, and the others for 1 foot increments thereafter to a final depth of 6 feet. The samples were weighed and dried in an oven at 110° C. and the dry weights were determined. The water content of a sample was expressed as percentage of the oven-dry weight of the soil. From the moisture percentages thus obtained the amounts of water in acre-inches per acre removed from each foot were computed by using the formula $D=\frac{MVd}{100}$, where M represents the moisture percentage, V the apparent specific gravity (volume-weight) of the soil, d the depth of soil in inches, and D the equivalent depth of water in acre-inches per acre.

The average apparent specific gravity and moisture equivalent determinations of the soils in the various field plots are shown respectively in tables 102 and 103.

TABLE 102.—*Results of apparent specific gravity determinations of soils in cotton and alfalfa plots at State College, N. Mex., 1936*

Plot	Crop	Apparent specific gravity					
		First foot	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot
Agronomy farm:							
Group I	Cotton	1.30	1.31	1.38	1.43	1.50	1.50
Group II	do	1.34	1.39	1.38	1.59	1.57	1.57
Field EC	do	1.32	1.15	1.23	1.23	1.23	1.23
Field 9W	do	1.36	1.48	1.29	1.37	1.37	1.40
Horticultural farm	Alfalfa	1.35	1.21	1.37	1.44	1.65	1.67

TABLE 103.—*Results of moisture equivalent determinations of soils in cotton and alfalfa plots at State College, N. Mex., 1936*

Plot	Crop	Moisture equivalent (percent)					
		First foot	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot
Agronomy farm:							
Group I	Cotton	28.94	19.55	13.25	7.25	4.66	3.17
Group II	do	16.32	15.34	11.74	7.81	6.07	4.38
Field EC	do	18.41	19.16	17.38	15.40	13.18	8.49
Field 9W	do	29.20	22.37	21.32	15.19	16.14	6.95
Horticultural farm	Alfalfa	23.89	31.18	13.75	13.07	3.46	2.85

Agronomy farm, cotton plots.—These plots were located on the cotton experimental field of the agricultural college agronomy department. The field was divided into 74 plots of one-fourteenth acre each. The soil ranges from a sandy loam to a clay loam. Soil samples were collected from 62 of the plots and soil moisture determinations were made. Each plot was irrigated with the same amount of water received by the others, the water applied being carefully measured over individual weirs.

For the purpose of this investigation, plots were divided into two groups, group I representing the heavier type soil and more luxuriant growth of cotton and group II a much smaller plant growth on a sandier soil. The difference in the surface 3 feet of soil in the two groups is indicated in table 103, which shows the average moisture-equivalent determinations for the different fields.

The average moisture content for the group I plots at various times during the 1936 season is given in table 104. The percent moisture loss during the sampling intervals was converted by means of the formula $D=\frac{MVd}{100}$, into soil moisture loss in acre-inches per acre, as shown in table 105. Rainfall was included in the total loss and the use (loss) of water per 30 days and for the interval between irrigations was calculated. The total use for the growing season, May 2 to October 19, was 29.63 acre-inches per acre. From evaporation records the use from October 19 to November 4 is estimated as 1.63 acre-inches per acre, making the total seasonal consumptive use 31.26 inches for group I cotton plots. The average yield for this group was 2,109 pounds of seed cotton per acre.

The data for group II are shown in like manner in tables 106 and 107. The use for the period between irrigations May 2 to June 6 has been estimated as 2.47 acre-inches per acre. For the period October 19 to November 4, the indicated use based on the preceding period is 2.30 inches. Thus the total seasonal consumptive use for group II plots is 25.67 acre-inches per

TABLE 104.—*Results of soil sampling and irrigation data, average for group I cotton plots, agronomy farm, State College, N. Mex., season 1936*

Dates of sampling	Average moisture content of soil (percent)							Dates of irrigation	Depth of irrigation water applied (inches)	Interval between irrigations (days)
	First 6 inches	Second 6 inches	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot			
May 19	19.97	19.97	16.82	13.69	9.50	10.00	9.75	May 2		
June 5	16.09	19.84	16.65	11.26	9.64	10.06	10.20	June 6	3	[illegible]
June 11	22.92	24.24	20.45	13.79	11.01	10.00	11.88			
July 1	13.03	17.31	16.95	11.98	9.88	9.14	8.24	July 3	[illegible]	27
July 7	26.40	22.63	17.82	13.71	9.69	9.77	8.61			
July 23	14.76	15.38	15.96	11.96	9.47	9.24	7.53	July 26	3	[illegible]
July 30	32.59	24.95	17.69	15.61	11.67	11.49	9.44			
Aug. 15	12.08	12.03	12.58	11.68	10.53	9.23	7.19	Aug. 15	4	[illegible]
Aug. 21	32.37	23.82	15.39	11.59	9.49	8.89	7.25			
Sept. 10	16.11	14.93	11.68	9.35	8.34	8.47	6.19	Sept. 13	4	29
Sept. 17	31.18	24.39	15.12	10.01	8.67	7.57	6.42			
Oct. 19	18.70	20.45	13.83	8.95	8.50	8.14	5.67	Oct. 19		36

TABLE 105.—*Quantities of water used in intervals between irrigations, group I cotton plots, agronomy farm, State College, N. Mex., season 1936*

Interval	[illegible]	Soil moisture loss (acre-inches per acre)										
		[illegible]	Second 6 [illegible]	Second foot	[illegible] foot	[illegible]	[illegible]	[illegible] foot	[illegible]	Total	[illegible]	Per 30 days
[illegible]	17	0.16	0.16	0.02	[illegible]	−0.02	−0.01	[illegible]	[illegible]	1.23	2.55	2.19
[illegible]	[illegible]	.77	[illegible]	[illegible]	.30	.19	.15	.65	.07	3.22	4.35	4.83
[illegible]	16	.91	[illegible]	.29	.29	.04	.09	.19	1.29	3.66	[illegible]	6.86
[illegible]	16	[illegible]	1.01	.80	[illegible]	.19	.41	.41	.18	[illegible]	6.56	[illegible]
[illegible]	[illegible]	1.27	[illegible]	.58	.37	.20	.07	.19	1.06	4.43	6.42	[illegible]
[illegible]	[illegible]	.97	.50	.20	.17	.03	−.10	.13	[illegible]	[illegible]	4.48	3.73

acre for the period May 2 to November 4. The average yield for this group was 1,228 pounds seed cotton per acre.

Field EC, Leding cotton plot.—This plot was located on the bench land south of the college buildings, where there was no possibility that a water table would influence the results. The soil is Anthony gravelly loam. The plant growth was unusually heavy on this plot. Soil sampling was not started until late in the season. The use of water on the Leding cotton plot for the period July 16 to October 21, 1936, is shown in table 108.

Field 9W, cotton plot.—This plot was located on the experimental field of the agricultural college's irrigation department. The area of the plot was 0.7 acre, and the soil is classed as Gila clay adobe, underlain by silt and sand. The water table ranged from 7 to 8 feet. Soil samples were taken at nine places uniformly spaced over the field. All irrigation water applied to this field was measured.

TABLE 106.—*Results of soil sampling and irrigation data, average for group II cotton plots, agronomy farm, State College, N. Mex., season 1936*

[illegible]	[illegible]							Dates of irrigation	Depth of irrigation water applied (inches)	[illegible] between irrigations [illegible]
	[illegible]	[illegible]	Second [illegible]	Third foot	[illegible] foot	[illegible]	[illegible] foot			
[illegible]	[illegible]	[illegible]						May 2	[illegible]	......
[illegible]	[illegible]	[illegible]	[illegible]	12.72	[illegible]	[illegible]	7.52	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	14.92	[illegible]	[illegible]	7.52			
July 1	[illegible]	[illegible]	[illegible]	13.12	10.49	[illegible]	6.23	July 3	[illegible]	27
July 7	[illegible]	[illegible]	17.34	15.83	9.55	9.51	7.55			
[illegible]	[illegible]	12.07	[illegible]	15.47	10.81	9.74	5.48	[illegible]	[illegible]	[illegible]
July 30	[illegible]	16.83	16.10	12.54	9.55	10.53	6.88			
Aug. 15	[illegible]	[illegible]	[illegible]	13.11	9.84	8.74	5.18	Aug. 15	4	[illegible]
[illegible]	[illegible]	18.05	[illegible]	14.90	10.78	8.75	7.44			
Sept. 10	[illegible]	14.20	[illegible]	[illegible]	10.05	[illegible]	[illegible]	Sept. 13	4	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	14.84	12.04	11.11	7.74			
[illegible]	[illegible]	15.17	[illegible]	11.35	[illegible]	10.41	[illegible]	[illegible]	......	[illegible]

TABLE 107.—*Quantities of water used in intervals between irrigations, group II cotton plots, agronomy farm, State College, N. Mex., season 1936*

Interval	[illegible]	[illegible]										
		[illegible]	[illegible]	[illegible]	Third [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	17	0.14	0.14						0.60	[illegible]	2.47	[illegible]
June 11 to July 1	[illegible]	[illegible]	.62	0.47	0.34	0.18	−0.27	0.24	.07	2.24	3.02	3.36
[illegible]	[illegible]	.68	.43	.16	.07	−.21	−.04	.36	[illegible]	[illegible]	3.94	5.14
[illegible]	[illegible]	[illegible]	[illegible]	.42	−.11	−.05	.34	[illegible]	[illegible]	[illegible]	3.36	5.05
[illegible]	[illegible]	.65	.31	.07	1.01	.12	−.30	.10	1.06	[illegible]	4.38	4.53
[illegible]	[illegible]	[illegible]	[illegible]	1.11	.67	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

TABLE 108.—*Quantities of water used in intervals between irrigations, Leding cotton plot, State College, N. Mex., season [illegible]*

Interval	[illegible]	[illegible] inches per acre)										
		[illegible] inches	[illegible] inches	[illegible] foot	Third foot	Fourth [illegible]	[illegible] foot	Sixth [illegible]	Rain in inches	Total	[illegible] irrigations	[illegible]
[illegible]	15	0.87	0.76	[illegible]	1.29	0.24	[illegible]	[illegible]	0.24	4.78	6.70	[illegible]
[illegible]	17	.83	.67	[illegible]	1.47	1.06	.82	[illegible]	[illegible]	7.36	9.10	[illegible]
[illegible]	[illegible]	.88	.71	1.57	.10	.31	.38	[illegible]	[illegible]	[illegible]	[illegible]	6.59
[illegible]	[illegible]	.06	.06	.11	.11	.03	.21	[illegible]	[illegible]	2.79	2.79	2.62

Tables 109 and 110 summarize the soil moisture data for cotton field 9W. It was necessary to estimate the soil moisture loss for the period April 27 to June 15 because no samples were taken immediately following the irrigation on April 27. The estimated values are based on the assumption that the first 2 feet had the same moisture content following the irrigation on April 27 that they had when the field was sampled after irrigation on June 17. Following the same reasoning applied to data from the other plots, the loss for the 14-day

TABLE 109.—*Results of soil sampling and irrigation data, field 9W, cotton plot, State College, N. Mex., season 1936*

Date of sampling	Average moisture content of soil, percent							Dates of irrigation	Depth of irrigation water applied (inches)	Interval between irrigations (days)
	First 6 inches	Second 6 inches	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot			
Apr. 27	17.60	17.60	12.10	10.63	8.31	10.30	6.54	Apr. 27	6.13	
June 13	15.35	25.95	18.82	11.30	8.07	10.52	3.68	June 15	[illegible]	[illegible]
June 17	28.04	29.13	21.34	15.20	8.73	9.98	4.58			
July 10	20.55	21.43	20.83	15.81	8.86	12.45	4.19	July 12	3.28	27
July 14	29.49	27.44	21.57	15.46	9.40	11.36	4.51			
Aug. 7	11.49	15.70	15.15	13.02	8.18	13.60	3.05	Aug. 8	4.76	27
Aug. 14	29.01	26.04	16.81	13.92	8.65	11.78	3.72			
Sept. 4	18.26	17.72	14.09	12.06	8.55	11.67	3.83	Sept. [illegible]	3.78	28
Sept. 11	29.53	27.76	17.29	13.03	7.69	9.48	5.10			
Oct. 21	14.52	16.95	14.66	11.27	7.40	9.25	4.33	Oct. 21		46

TABLE 110.—*Quantities of water used in intervals between irrigations, field 9W, cotton plot, State College, N. Mex., season 1936*

Interval	Number of days	Soil moisture loss (acre-inches per acre)										
		First 6 inches	Second 6 inches	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot	Rain, inches	Total	Between irrigations	Per 30 days
Apr. 27 to June 13	47	1.04	0.31	0.41					0.77	[1] 2.53	[1] 2.[illegible]	[1] 1.62
June 17 to July 10	23	.60	[illegible]	.09	0.06	−0.02	−0.40	0.07	1.36	2.39	2.81	3.12
July 14 to Aug. 7	24	1.47	.91	1.05	.40	.20	−.36	.24	.32	4.23	4.76	5.29
Aug. 14 to Sept. 4	21	.88	.69	.44	.30	.17	.17	−.17	1.30	3.78	5.04	5.40
Sept. 11 to Oct. 21	40	1.22	.88	.43	.19	.05	.04	.13	2.09	5.03	5.79	3.77

[1] Estimated.

TABLE 111.—*Results of soil sampling and irrigation data, alfalfa plot, horticultural farm, State College, N. Mex., season 1936*

Dates of sampling	Average moisture content of soil, percent							Dates of irrigation	Interval between irrigation, days	Dates of cutting
	First 6 inches	Second 6 inches	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot			
										May 15
June 17	24.45	19.36	20.33	10.27	7.66	3.13	3.46	June 5		
June 25	11.10	11.30	14.13	8.79	5.81	3.01	3.43	June 26	21	June 23
June 30	23.26	20.31	21.24	13.78	8.73	3.86	3.62			
July 9	18.32	13.01	16.68	10.15	7.13	3.21	3.83	July 10	14	
July 14	21.93	17.94	12.79	7.55	5.97	2.43	3.33			
July 23	9.28	8.84	11.29	7.13	5.79	2.59	3.47	July 2[illegible]	1[illegible]	
July 30	21.25	15.59	12.42	10.08	8.39	2.67	4.27			
Aug. 5	Sampling lost							Aug. 6	1[illegible]	Aug. 3
Aug. 11	23.82	21.18	14.63	7.81	6.77	2.93	3.14			
Aug. 20	13.71	12.88	16.11	6.81	7.27	2.54	2.81	Aug. 21	15	
Aug. 25	23.04	19.14	17.95	10.21	7.57	3.30	3.72			
Sept. 9	12.28	11.95	13.84	7.35	5.01	2.52	3.09	Sept. 13	23	Sept. 15
Sept. 16	22.04	16.95	12.93	6.88	7.06	2.75	3.54			
Oct. 2	21.61	19.58	15.59	6.73	6.04	2.88	3.59	Oct. 3	20	
Oct. 7	23.50	21.67	21.62	10.21	7.70	3.54	3.61			
Oct. 21	13.06	14.81	21.84	9.20	8.59	3.80	3.73	Nov. 4	32	Nov. [illegible]

TABLE 112.—*Quantities of water used in intervals between irrigations, alfalfa plot, horticultural farm, State College, N. Mex., season 1936*

Interval	Number of days	Soil moisture loss (acre-inches per acre)										
		First 6 inches	Second 6 inches	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot	Rain in inches	Total	Between irrigations	Per 30 days
June 17 to June 25	8	1.05	0.65	0.90	0.24	0.32	0.02	0.01	0.07	3.26	8.56	12.22
June 30 to July 9	9	.40	.59	.66	.60	.28	.13	−.04	.98	3.60	5.60	12.00
July 14 to July 23	9	1.02	.74	.22	.07	.03	−.03	−.03	0	2.02	3.37	6.74
Aug. 11 to Aug. 20	9	.01	.67	−.21	.16	−.08	.08	.07	.15	.85	1.42	2.83
Aug. 25 to Sept. 9	15	.87	.57	.60	.47	.44	.16	.12	1.03	4.26	6.53	8.52
Sept. 16 to Oct. 2	16	.04	−.21	−.39	.02	.18	−.03	−.01	2.08	1.68	2.10	3.15
Oct. 7 to Oct. 21	14	.84	.55	.03	.16	−.15	−.05	−.02	0	1.36	3.11	2.92

period October 21 to November 4 was estimated as 1.45 inches. On this basis the total consumptive use for the period April 27 to November 4 is estimated to have been 22[illegible] acre-inches per acre.

Horticultural farm, alfalfa plot.—This plot was located in an alfalfa field on the horticultural farm. The soil is a Gila silt loam with sand at the lower depths. The average apparent specific gravity and moisture equivalent determinations are shown in tables 102 and 103. Samples were collected from six locations in the field plot. The alfalfa had been planted in 1935, and there was a good stand. The results of the soil moisture studies are summarized in tables 111 and 112. Because some of the early and midsummer soil samples were not taken before irrigation the records are not complete. However the results show monthly use of water by alfalfa in the plot ranged from 12.22 inches in June to 2.92 inches in October. It is estimated that the use from May 1 to November would not exceed 52 acre-inches per acre.

[illegible]

Cotton and Alfalfa Tank Experiments

In the latter part of May 1936, four tanks were installed at State College to determine the evapo-transpiration of cotton and alfalfa. Two tanks were used for each crop. The tanks were of the double type similar to those used in the Middle Valley (p. 371), but were not as deep (3). The inner tank, 23 1/16 inches in diameter by 42 inches deep, was suspended in a water-tight outer tank (approximately 25½ inches in diameter by 48 inches deep) by means of a heavy angle-iron rim around the top. The inner tank had a removable bottom and was filled with soil by being driven down into the ground, so cutting out a core of the undisturbed soil. Soil was removed from around the tank as the shell was driven, and when the tank was filled nearly to the top, the removable bottom plate was replaced and bolted on the tank, which was then hoisted by means of a large tripod and chain block. The outer tank was set in place and the inner tank, full of soil, was lowered into it. Numerous holes in the sides and bottom of the inner tank allowed water to move freely to or from the soil.

In operation, water was added in the annular space between the tanks until the soil was completely saturated and water stood in both tanks at a zero point (p. 348). The excess water was then pumped out and measured. At the next irrigation the quantity of water necessary to bring the water level again to the zero point was measured. The difference between the quantity removed the previous time and that added gave the amount that had been used by evaporation and transpiration.

Cotton.—Two tanks were placed in the cotton field 9W plot, where soil moisture studies previously described were made (p. 390). The water level in the outer tank was kept below the soil column in the inner tank, so that no water would be supplied by capillary action. It was intended to have two plants in each tank, but one plant was destroyed in the west tank early in the season. The plants were smaller than the adjacent plants in the field. Use of water by the cotton tanks during the period June 6 to November 7, 1936, is shown in table 113.

For the west tank with one plant the use amounted to 25.96 inches, and for the east tank, with two plants, 32.22 inches; the average, 29.09 inches. By comparison with the use determined by the soil moisture work, it is estimated that the tanks would have lost 2.5 inches from May 1 to June 5, making the total seasonal use,

TABLE 113.—*Consumptive use of water for cotton tanks, State College, N. Mex., 1936*

Period	Number of days	Consumptive use of water per acre (inches)[1]				Precipitation, inches
		Inches		Average		
		West tank	East tank	Period	Per 30 days	
June 6 to July [illegible]	[illegible]	3.13	[illegible]	[illegible]	[illegible]	0.11
July [illegible] to Aug. [illegible]	[illegible]	8.61	[illegible]	[illegible]	7.45	1.58
Aug. [illegible] to Sept. [illegible]	28	6.53	6.63	6.58	7.05	1.33
Sept. [illegible] to Nov. [illegible]	[illegible]	7.69	11.39	[illegible]	[illegible]	2.49
Total	144	25.96	32.22	[illegible]		[illegible]

[1] Including precipitation.

including rain, 31.6 inches.[19] Yields of seed and cotton were 88.4 grams from 11 bolls for the east tank and 87.3 grams from 13 bolls for the west tank. Dry weights for the cotton stalks cut flush with the ground were 190 grams for the east tank and 99 grams for the west tank.

Alfalfa.—Two tanks were set near the center of the horticultural farm alfalfa field. The results indicated an excessive use of water and seem unreasonable. Thus, they are not included herein as they do not represent Valley conditions and would be misleading. However, they indicate that the maximum annual use of water by alfalfa with high water table may exceed 6 acre-feet per acre.

Native Vegetation and Evaporation Experiments

In some sections of the Lower Valley, growths of natural vegetation such as willows, salt cedar, cottonwoods, tules (cattails) and salt grass use considerable water. Perhaps the heaviest evapo-transpiration loss per unit area within the Valley occurs through the vigorous growths of cottonwood, tules, and willows along the river channels. No experiments prior to the 1936 group had been made to determine use of water by native vegetation in Lower Valley, such as those in the Middle Valley and San Luis Valley. However, records of evaporation from a standard Weather Bureau pan have been kept by the agricultural experiment station at State College for many years (table 118), and these records are of value in estimating past and future use of water if correlated with evapo-transpiration losses (3).

Early in May 1936, the Bureau of Agricultural Engineering established an evapo-transpiration and evaporation station at Mesilla Dam, about 5 miles southwest of State College, on a site made available by the Bureau of Reclamation.[20] The site was on low ground on the west bank of the Rio Grande, approximately 100 yards above the dam, in an area of tules (cattails) and salt grass. The exposure was open in all directions except to the west, where the mesa rises abruptly about 15 feet some 50 yards from the station. To the south were a few scattered trees, while the river bordered the northeast side. A sketch of the station site is shown as figure 94.

The two cattail tanks (nos. 1 and 2) were located in a tule swamp and completely surrounded by natural growth. Both tanks were 2 feet in diameter and 3 feet

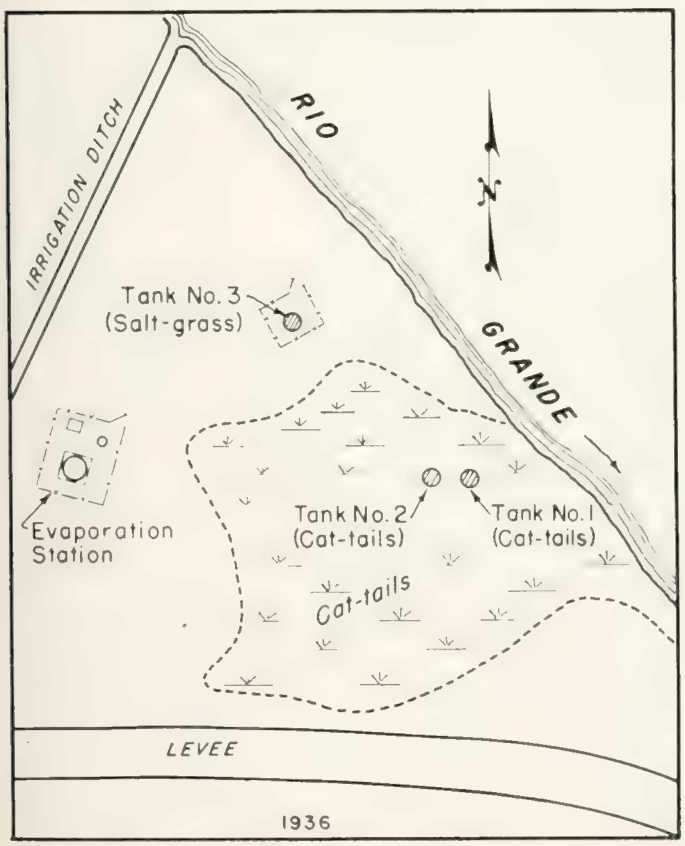


FIGURE 94.—Plan of Mesilla Dam station.

FIGURE 95.—Mesilla Dam evapo-transpiration station. [illegible]

[19] See p. 389 for consumptive use determined by soil moisture studies.

[20] Through the courtesy of L. R. Fiock, superintendent, Rio Grande Project.

[illegible] The tanks were partly filled with sand before [illegible] of healthy broadleaf cattails (*Typha latifolia* L.) were transplanted into them with as little shock to the plants as possible. The water level was maintained in the tanks above the surface of the soil. Each tank contained about 42 stalks of cattails. Both tanks developed a vigorous growth but the plants in tank no. 1 grew the larger.

Tank no. 3, containing salt grass, was installed in a nearby plot of salt grass where the ground water was close to the surface. The tank had a diameter and a depth of 3 feet. It was partly filled with sand before the salt grass (*Distichlis stricta* Hydb.) sod was transplanted. A Mariotte control provided an automatic supply of water to tank no. 3, keeping the water level at a fairly constant depth of 14 inches below the surface of the soil. A thick growth of grass developed, covering the surface and attaining a height of 7 to 10 inches by midsummer.

A standard Weather Bureau evaporation pan and 8-inch rain gage were installed at the station. A thermograph, located at the station for a portion of the summer, did not function properly. Temperature records are therefore not available.

Table 114 shows weekly evapo-transpiration losses from cattail and salt grass tanks and evaporation records. A summary of monthly results at Mesilla Dam station for the 6-month period, June to December 1936, together with evaporation and meteorological data at State College station are shown in table 115.

Table 114.—[illegible] precipitation at Mesilla Dam station, Mesilla Valley, N. Mex., [illegible]

[illegible]	Consumptive use [illegible]: Tank no. [illegible]	Tank no. [illegible]	Tank no. [illegible]	Evaporation, inches ([illegible] Bureau pan)	Precipitation [illegible]
May 11				[illegible]	
[illegible]				[illegible]	
[illegible]				[illegible]	.67
[illegible]				[illegible]	.23
June 8				[illegible]	
[illegible]	[illegible]				
[illegible]				[illegible]	[illegible]
[illegible]	5.32				[illegible]
[illegible]	[illegible]				
[illegible]	4.04				[illegible]
[illegible]	[illegible]		[illegible]	2.28	[illegible]
[illegible]	4.73	2.83	2.09	2.19	0
[illegible]	3.67	2.38	1.73	[illegible]	.16
[illegible]	4.29	[illegible]	2.09	2.14	.02
[illegible]	4.51	3.46	1.58	2.10	0
[illegible]	2.90	2.47	1.37	1.79	.31
[illegible]	[illegible]	2.40	2.12	1.84	.35
[illegible]	[illegible]	[illegible]	1.65	1.85	.05
[illegible]	[illegible]	2.32	[illegible]	1.70	.70
[illegible]	[illegible]	2.15	1.53	1.73	.97
[illegible]	1.71	[illegible]	1.17	[illegible]	0
October 5	1.35	[illegible]	1.07	1.25	0
[illegible]	1.27	1.17	1.11	[illegible]	0
[illegible]	.72	.68	.89	1.07	0
[illegible]	[illegible]	[illegible]	.67	[illegible]	.35
[illegible]	[illegible]	.48	.47	1.01	[illegible]
[illegible]	.81	.60	.33	[illegible]	0
[illegible]	[illegible]	.45	[illegible]	.81	0
[illegible]	.50	.31	[illegible]	.61	.21
[illegible]	[illegible]	.47	[illegible]	.35	.78
[illegible]	.47	[illegible]	.46	.46	[illegible]
[illegible]	[illegible]	[illegible]	.08	.38	[illegible]
[illegible]	.46	.32	[illegible]	[illegible]	0
[illegible]	.35	.31	.17	.43	[illegible]

[illegible]

[illegible] R. Fiock and A. S. [illegible]

Evaporation From Free Water Surfaces [21]

The processes of evaporation and transpiration are similar in that each is influenced by climatic conditions. Hence the relation between consumptive use of water by vegetation and evaporation from water surfaces is too apparent to be overlooked in any discussion of water requirements. In the Rio Grande Basin above El Paso both evapo-transpiration and evaporation become progressively smaller as elevation increases and the growing season shortens.

Long Period Records

The Weather Bureau has maintained standard evaporation stations at Santa Fe, Elephant Butte Dam, and State College for many years. Results of observa-

[illegible]

[21] [illegible]

Table 115.—[illegible] native vegetation, evaporation, and meteorological data in Mesilla Valley, N. Mex., [illegible]

Month	[illegible] Tank no. [illegible] in water	Tank no. [illegible] in water	Tank no. [illegible]	Mesilla Dam	State College	Temperature (° F.): Mean maximum	Mean minimum	Mean	Wind [illegible]: Total miles	Average m. p. h.	[illegible] relative humidity (percent)
				([illegible] (Weather Bureau pan))							
[illegible]	[illegible]	[1] 14.90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	7.90	[illegible]	10.43	[illegible]	[illegible]	[illegible]	2,169	2.91	[illegible]
[illegible]	[illegible]	[illegible]	6.11	[illegible]	7.29	[illegible]	[illegible]	[illegible]	1,501	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	5.37	[illegible]	74	[illegible]	[illegible]	1,447	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1.21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.93	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,214	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]						

[illegible]

tions at Santa Fe (elevation 7,013 feet) are shown in table 116. This station was discontinued in 1933. Records at Elephant Butte Dam (elevation approximately 4,500 feet) collected in cooperation with the Bureau of Reclamation from January 1917 to December 1936, are given in table 117. Observations shown in table 118 for State College (elevation 3,863 feet), from January 1919 to December 1936, were made cooperatively with New Mexico Agricultural Experiment Station.

TABLE 116.—*Evaporation in inches, Weather Bureau pan, Santa Fe, N. Mex., January 1917 to December 1933, inclusive*

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1917	3.138	2.881	5.583	7.216	7.642	11.890	9.955	9.038	6.786	5.937	3.355	2.391	75.815
1918	1.083	2.305	3.809	6.129	9.775	10.240	9.294	8.172	6.685	4.295	1.958	1.466	65.211
1919	1.587	1.023	2.699	5.496	8.289	9.381	6.810	7.467	5.434	3.837	2.803	1.571	56.397
1920	1.592	2.101	3.911	5.566	8.515	9.040	8.608	7.505	6.527	4.645	2.012	1.708	61.720
1921	1.381	2.324	4.532	6.439	8.879	8.683	8.129	6.636	6.913	4.930	3.256	1.478	63.580
1922	1.418	2.158	3.600	5.768	10.185	10.154	10.259	8.923	7.120	5.182	1.856	1.263	68.186
1923	1.807	.959	3.441	6.279	8.579	10.603	8.713	6.711	4.770	3.815	1.970	1.061	58.748
1924	.925	2.240	2.962	5.639	8.346	11.989	8.811	9.277	7.756	6.147	3.298	1.201	68.591
1925	1.537	2.280	5.075	8.215	9.007	10.286	9.533	7.470	6.751	4.473	2.026	.773	67.426
1926	.834	3.008	3.941	4.756	5.923	8.784	9.180	9.443	6.708	4.828	2.929	1.022	61.356
1927	1.715	2.098	4.029	6.698	12.244	9.312	9.306	8.094	5.463	5.286	2.873	1.084	68.202
1928	1.451	1.928	4.314	6.021	6.842	11.214	10.008	7.550	7.512	4.580	1.594	1.665	64.679
1929	1.259	1.947	3.733	7.049	9.666	11.852	8.411	6.865	6.620	4.511	1.893	1.407	65.213
1930	1.402	2.710	3.605	7.279	8.587	10.745	8.187	7.220	6.862	4.281	1.928	1.200	64.006
1931	1.232	2.464	3.731	5.502	8.629	10.730	8.992	7.429	5.534	4.510	2.174	1.822	62.749
1932	1.831	2.555	3.441	7.058	8.808	9.995	9.151	5.591	4.689	2.443	[1] 2.080	[1] 2.080	59.722
1933	[1] 1.350	[1] 2.360	4.355	[1] 6.470	7.658	8.360	8.888	7.648	6.393	3.907	[1] 1.130	[1] 1.130	59.649
Average	1.502	2.197	3.927	6.328	8.681	10.209	8.957	7.708	6.384	4.565	2.302	1.431	64.191

[1] Estimated.

TABLE 117.—*Evaporation in inches, Weather Bureau pan, Elephant Butte Dam, N. Mex., January 1917 to December 1936, inclusive*

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1917	2.143	4.135	9.642	12.925	13.498	15.289	13.247	11.808	9.003	8.918	5.122	3.962	109.692
1918	3.179	5.645	8.214	11.321	15.714	14.250	13.544	11.604	10.170	6.721	3.686	.994	105.042
1919	1.402	3.459	7.203	9.193	12.665	12.677	11.145	11.129	7.878	7.817	3.976	2.734	91.278
1920	1.920	3.912	8.369	10.473	14.165	12.474	13.505	10.661	9.955	8.631	3.656	3.467	101.188
1921	3.556	4.876	8.156	10.982	14.265	13.069	10.242	9.870	9.745	9.408	5.336	3.678	103.183
1922	3.669	5.537	8.059	11.194	14.338	14.086	13.851	12.191	8.969	7.631	3.799	2.749	106.073
1923	3.851	3.314	6.764	11.097	14.490	17.063	12.327	9.097	7.830	7.445	2.765	3.835	99.878
1924	2.548	3.852	7.644	8.755	11.569	14.966	10.737	11.395	10.568	8.650	5.044	2.784	98.512
1925	2.437	4.656	8.237	11.077	11.743	15.383	11.960	10.795	9.288	6.813	4.148	2.509	99.046
1926	1.734	4.901	5.295	6.992	9.829	13.163	12.016	11.005	7.269	5.933	4.152	1.958	84.247
1927	3.090	4.758	7.846	10.220	14.833	13.421	12.375	8.983	7.611	6.610	4.743	2.422	96.912
1928	2.797	2.801	7.707	9.096	9.814	14.483	12.101	9.624	8.316	5.866	2.752	2.184	87.541
1929	3.447	4.192	7.307	11.126	12.009	14.197	9.928	7.981	7.488	4.535	2.506	2.312	87.028
1930	2.515	4.369	6.229	9.750	11.713	12.009	9.580	9.100	8.093	6.366	3.051	1.783	84.558
1931	1.725	2.251	6.747	6.712	10.338	11.560	10.419	8.326	6.539	5.895	3.480	1.985	75.977
1932	2.242	4.678	6.197	9.606	11.205	11.857	9.720	8.990	7.870	4.715	3.639	2.228	82.947
1933	2.337	3.179	7.219	8.287	11.768	9.932	13.105	11.174	9.892	6.647	4.508	3.841	91.889
1934	3.286	5.228	8.574	11.274	14.783	17.480	16.690	14.085	11.298	8.288	4.937	2.698	118.621
1935	3.224	4.175	9.199	12.304	12.576	16.805	15.967	10.850	8.049	8.502	4.855	2.404	108.910
1936	2.988	5.652	9.110	12.095	14.068	17.409	14.496	14.215	9.656	8.014	4.645	3.598	115.946
Average	2.704	4.278	7.686	10.224	12.769	14.786	12.348	10.644	8.774	7.170	4.040	2.706	97.423

TABLE 118.—*Evaporation in inches, Weather Bureau pan, State College, N. Mex., January 1919 to December 1936, inclusive*

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1919	2.652	4.187	7.751	9.910	12.251	13.502	12.892	11.477	7.474	5.531	3.895	2.664	94.186
1920	2.225	4.054	7.465	10.395	11.993	11.618	12.899	9.885	8.945	6.103	3.009	3.130	91.721
1921	3.797	4.584	8.597	10.232	11.638	12.353	10.535	9.596	7.843	6.352	4.379	3.228	93.134
1922	3.301	5.838	8.243	10.107	12.688	13.615	13.237	11.022	8.081	5.717	3.450	2.715	98.014
1923	3.374	2.934	6.883	9.551	12.359	11.275	11.300	8.946	7.094	6.179	3.003	1.852	84.750
1924	2.945	4.391	7.090	8.146	10.105	12.086	9.056	9.722	8.924	7.082	4.183	2.436	86.166
1925	2.734	5.343	8.077	9.388	8.691	10.238	9.139	8.351	6.805	4.990	3.496	2.387	79.639
1926	1.914	4.647	5.151	7.294	9.038	10.558	10.126	9.296	7.239	4.590	3.627	2.086	75.566
1927	3.216	4.424	7.249	9.278	11.636	10.276	10.294	7.886	6.840	5.802	4.378	2.173	83.452
1928	3.027	4.148	8.165	9.075	9.525	11.780	10.823	7.801	6.924	5.218	2.671	2.777	81.934
1929	3.210	4.314	7.109	8.877	10.410	11.604	9.124	7.749	7.052	5.008	2.594	2.550	79.601
1930	2.749	4.740	6.429	8.541	10.864	11.890	9.896	9.050	7.760	5.931	3.744	2.172	83.766
1931	2.586	2.992	7.150	7.728	10.841	11.921	10.247	8.487	7.484	6.883	3.557	2.845	82.721
1932	2.993	3.999	7.631	11.204	13.364	14.218	13.403	12.257	9.420	5.663	4.179	2.499	100.830
1933	2.747	4.158	9.413	10.280	14.152	12.284	13.542	11.077	9.787	6.202	4.139	3.543	101.324
1934	3.222	4.989	7.755	11.117	12.927	14.538	14.945	13.097	10.479	7.211	4.681	2.825	107.786
1935	3.454	3.934	8.413	11.607	11.663	15.097	15.374	12.019	7.428	7.184	4.411	2.622	103.206
1936	3.588	5.262	9.068	10.853	13.308	15.333	12.605	10.429	7.293	5.633	3.653	2.556	99.581
Average	2.985	4.386	7.647	9.644	11.525	12.455	11.635	9.897	7.937	5.960	3.725	2.614	90.410

1936 Records

During the season of 1936 the Bureau of Agricultural Engineering installed standard Weather Bureau pans at the San Luis Lakes, Parma, and West stations in San Luis Valley (pp. 361 and 362), at El Vado Dam, Isleta, and Socorro in the Middle Valley (pp. 375 and 376); and at Mesilla Dam (p. 393) in the Lower Valley, to correlate evapo-transpiration losses in wet areas with evaporation from free water surfaces. Weekly and monthly evaporation at various places in each of the three valleys are summarized in tables 119 and 120.

For further comparison, monthly evaporation at Parma, Isleta, Socorro, and Mesilla Dam has been computed as a percentage of the loss at State College for the season of 1936 and presented by months in table 121. At State College and at Mesilla Dam evaporation records were obtained from the middle of May to the end of December, but at other stations, because of freezing weather, records for the colder months were incomplete. The State College station is used as the basis of comparison because records are available for a 17-year period. A peculiar feature is that evaporation at Mesilla Dam is but 85 percent of that indicated by the State College record, despite the fact that the two locations are only 5 miles apart. This difference can be accounted for principally by the fact that State College station is located higher in the Valley in a bare field, away from vegetation and fully exposed, while the Mesilla Dam station was located on the river bank in a wet area in the midst of vegetation. The stations at Parma, Isleta, Socorro, and Mesilla Dam were located in river areas having comparable environments.

TABLE 119.—Weekly evaporation in inches, Weather Bureau pans, Upper Rio Grande Basin, season of 1936

[illegible]	San Luis Valley, Colo.			Middle Rio Grande Valley, N. Mex.				Lower Valley, N. Mex.		
	San Luis Lakes	Parma	West	[illegible]	El Vado Dam	Isleta	Socorro	Elephant Butte Dam	State College	Mesilla Dam
[illegible]				[illegible]				[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]		2.12		[illegible]		[illegible]	[illegible]	[illegible]
June 1	[illegible]	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]
[illegible]	2.06	1.93		[illegible]		[illegible]	[illegible]	[illegible]	3.22	3.00
[illegible]	2.76	1.93		[illegible]		[illegible]	[illegible]	3.82	[illegible]	3.33
June 22	2.87	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	4.29	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	2.31	[illegible]	[illegible]	[illegible]	[illegible]	3.74	3.27	3.05
July 6	[illegible]	[illegible]	[illegible]	1.71	2.30	2.38	[illegible]	[illegible]	3.57	[illegible]
July 13	[illegible]	1.47	2.24	1.67	[illegible]	[illegible]	[illegible]	3.29	2.92	[illegible]
[illegible]	[illegible]	1.59	2.36	[illegible]	[illegible]	[illegible]	2.09	3.24	[illegible]	[illegible]
[illegible]	2.27	1.47	2.13	1.98	1.99	[illegible]	2.31	3.37	[illegible]	2.49
[illegible]	[illegible]	1.11	1.49	1.45	1.81	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	1.30	[illegible]	1.48	1.43	2.03	[illegible]	[illegible]	[illegible]	2.14
[illegible]	1.98	[illegible]	[illegible]	1.75	2.07	[illegible]	[illegible]	3.93	2.57	2.10
August [illegible]	1.42	[illegible]	1.44	1.60	[illegible]	1.81	[illegible]	[illegible]	1.85	[illegible]
[illegible]	[illegible]	1.39	1.56	1.34	1.96	[illegible]	[illegible]	[illegible]	[illegible]	1.84
[illegible]	1.88	1.70	1.82	1.79	[illegible]	1.81	1.84	[illegible]	2.09	1.85
[illegible]	[illegible]	1.15	[illegible]	[illegible]	1.18	1.63	1.67	[illegible]	1.89	[illegible]
[illegible]	1.41	[illegible]	1.23	.97	1.41	1.50	1.45	2.02	1.74	[illegible]
[illegible]	[illegible]	.71		.88	[illegible]	1.60	1.08	1.84	[illegible]	1.04
[illegible]	[illegible]			1.14	1.20	[illegible]	1.14	[illegible]	1.47	1.25
[illegible]	[illegible]	1.85	[illegible]	.90	.95	1.16	1.17	[illegible]	1.53	1.33
[illegible]	[illegible]	[illegible]		.76	[illegible]	1.09	1.27	2.09	1.32	1.07
[illegible]	.51	[illegible]		[illegible]	.42	.87	.70	1.27	.93	[illegible]
November 2	[illegible]	.54		.60	.52	.88	1.00	1.74	1.24	1.01
[illegible]	[illegible]	.42				.78	.89	[illegible]	.95	1.12
[illegible]	[illegible]	[illegible]				[illegible]	.83	[illegible]	[illegible]	.81
[illegible]	.43	[illegible]				[illegible]	.85	.90	[illegible]	[illegible]
[illegible]	.28	[illegible]				[illegible]	.43	[illegible]	.46	[illegible]
[illegible]								[illegible]	[illegible]	.40
[illegible]								[illegible]	[illegible]	.38
[illegible]								[illegible]	[illegible]	[illegible]
[illegible]								[illegible]	[illegible]	[illegible]

TABLE 120.—Monthly evaporation in inches, Weather Bureau pans, Upper Rio Grande Basin, season of 1936

Month	San Luis Valley, Colo.			Middle Rio Grande Valley, N. Mex.				Lower Valley, N. Mex.		
	San Luis Lakes	Parma	West	[illegible]	El Vado Dam	Isleta	Socorro	Elephant Butte Dam	State College	Mesilla Dam
[illegible]	[illegible]	[illegible]		[illegible]		14.86		16.42	[illegible]	[illegible]
June	10.84	[illegible]		[illegible]	[illegible]	11.07	[illegible]	17.41	[illegible]	14.11
July	9.33	[illegible]	9.47	7.96	[illegible]	[illegible]	10.60	14.50	[illegible]	10.53
[illegible]	7.76	[illegible]	6.67	6.79	[illegible]	9.05	[illegible]	[illegible]	10.43	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	5.27	[illegible]	[illegible]	6.19	[illegible]	7.29	[illegible]
October	[illegible]	3.22		3.85	[illegible]	[illegible]	4.64	8.01	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]								[illegible]	[illegible]	[illegible]

TABLE 121.—*Comparative monthly evaporation, Weather Bureau pans, Upper Rio Grande Basin, season of 1936*

Month	Evaporation at State College inches	Ratio of evaporation at other stations to evaporation at State College, percent			
		Parma, Colo.	Isleta, N. Mex.	Socorro, N. Mex.	Mesilla Dam, N. Mex.
May	[illegible]	[illegible]	[1] 82.[illegible]		71.[illegible]
June	15.33	53.9	72.2	79.4	92.0
July	12.60	51.7	79.8	84.1	83.6
August	10.48	65.4	86.8	88.9	86.7
September	7.29	64.[illegible]	90.8	84.9	90.0
October	5.63	77.2	81.7	82.4	95.4
November	3.67	40.8	80.8	87.7	83.3
December	2.56				77.7
Average	8.[illegible]	57.5	82.1	84.6	85.0

[1] May 11 to June 1.
[2] May 18 to June 1.

The evaporation at Isleta, Socorro, and Mesilla Dam differs but little, although the locations are many miles apart. The close agreement of these three records and their departure from the records for State College indicate that evaporation at State College is not representative of evaporation in wet areas of the Valley below Albuquerque.

The evaporation in San Luis Valley (elevation 7,000 to 8,000 feet) is considerably less than that in the Middle Valley (elevation 4,890 feet) and Lower Valley (elevation 3,863 feet). The reason for this striking difference is apparent in part when the lengths of growing seasons and differences in elevations and temperatures are considered. In San Luis Valley the average frost-free period is 108 days, in Middle Valley at Albuquerque 196 days, at State College a minimum of 200 days.

Pan Coefficient

Previous to 1915, little attempt had been made to determine the relationship existing between pans of different sizes and large water surfaces. In 1915 the Bureau of Agricultural Engineering established a laboratory at Denver (57) for this purpose, and has carried on research studies of evaporation (3) (54) at various places since that time.

Coefficients for reducing standard Weather Bureau pan records vary, but for the Upper Rio Grande Basin it is recommended that 0.70 be used.

Relation of Evaporation to Consumptive Use

Meteorological conditions influencing evaporation from water surfaces likewise affect transpiration from vegetation and evaporation from soils. Both evaporation and transpiration freely respond to temperature, wind movement, and humidity, so that evaporation from water may, under certain conditions, be used as an index of transpiration or soil evaporation losses.

Observed evaporation data may be used as a means of estimating evapotranspiration by water-loving vegetation when the relation of the two values is known for a particular area. This relation, during the growing season, is not constant, yet it provides a means of making approximate comparisons of consumptive use, not only from year to year, but between adjacent localities.

As an example of the adaptability of the evaporation pan in estimating consumptive use, the results of an investigation by the Bureau of Agricultural Engineering at Victorville, Calif., may be cited (3). For tules growing in a large tank within the confines of a swamp area the percentage of consumptive use with reference to evaporation from a nearby exposed Weather Bureau pan was 95 percent.[23] Neglecting such factors as variety, density of growth, and seasonal variations in evaporation and transpiration, this percentage was applied to evaporation records in other portions of the same general locality. It is probable, however, that this relation is not a constant but varies from year to year and for different geographical areas. The fact that both evaporation and consumptive use do so vary lends support to this conclusion. The climate at Victorville is very similar to that of the Middle Rio Grande Valley.

Accepting such a ratio for the Victorville area, it is reasonable to suppose that it might be applied also to evaporation records from Weather Bureau pans in other areas in order to estimate consumptive use by tules growing in swamps in those areas. It should be emphasized, however, that comparisons of transpiration and evaporation should be extended only to those areas where vegetation is subject to similar seasonal climatic conditions.

[23] The percentage varied from month to month, increasing during the summer and becoming smaller in the cooler months, but 95 percent was the average obtained from a 2-year record.

PART III

SECTION 5.—CANAL DIVERSIONS IN RELATION TO MAPPED AREAS

Because of differences in environment, diversions by a particular canal may or may not be closely related to consumptive use in an area served by a canal in another part of the Valley. Therefore the ditches and canals are grouped below in accordance with their environmental characteristics.

1. *Mountain valley ditches.*—These divert relatively large amounts of water, and irrigate lands immediately between them and the streams from which they divert. With the usual open mountain soils, narrow valleys, and steep lateral gradients, the amounts diverted are relatively unimportant because it can be assumed that nearly all water in excess of the actual consumptive use will return to the stream and become available for rediversion and use lower in the stream system. The total area under such irrigation is small compared with that under large canal systems in the main valleys.

2. *Valley floor canal systems.*—These are of three types: (a) Those irrigating lands topographically and geologically so situated that water diverted but not consumptively used can be assumed to return, in variable proportions, to the parent stream, or to the main river—a process which has been greatly aided by extensive drainage systems. This type comprises most of the land in San Luis Valley south of the closed area and all the land along the Rio Grande in New Mexico and Texas. (b) Those diverting water from the main Rio Grande or its tributaries, but conveying this water into the closed area in San Luis Valley from which there is no return flow to the main river system, except a small amount coming back through Rio Grande drain. (c) Those diverting waters from streams flowing into the closed area and irrigating lands subject to gravity return of waters to the sump of the closed area. There is, however, little or no surface return to the sump from the north and west except in very wet years. The measured diversions in this closed area are further complicated by the existence of several thousand artesian wells, most of which run wild the year round. Similar wells exist in the San Luis Valley areas southwest of the Rio Grande, outside of the closed area. (Pl. 11.)

San Luis Valley

In the closed area the west and east sides have different characteristics.

Two streams, La Garita and Carnero Creeks, come out from the hills on the west and irrigate a small area above the Rio Grande Canal, bringing water from the Rio Grande. Return waters probably mingle with those from Saguache Creek and from Rio Grande Canal lands and contribute to the drainage waters of the Rio Grande Drainage Canal.

Saguache Creek heads in the Continental Divide and irrigates a large area of land around Saguache. In some years excess flow penetrates to the lower end of Saguache Creek where it joins San Luis Creek. The latter heads in Poncha Pass and one tributary of importance, Kerber Creek, enters from the west near Villa Grove.

From the eastern side a large number of small streams head in the Sangre de Cristo Mountains, debouch onto the Valley from steep mountain gorges and are used to irrigate lands along the fringe of the hills between San Luis Creek and the mountains. Hay and pasture are the principal crops. For many of the streams in this group the discharge records were first obtained in 1936. There has been much speculation in the past as to yield of these streams. The record of one year, of course, is not sufficient to use as the basis of determining the mean annual run-off from this part of the watershed. Furthermore, in years of plenty, the hay crop will be heavier and the consumptive use greater than in years of shortage. Under these conditions it is difficult to offer a set figure as the consumptive requirements. Return flow from this extensive area must all accumulate in the large sump of the closed area located in its southerly portion.

Much of the grasslands and low brush lands lying along lower San Luis Creek, while not irrigated in the usual sense of the word, undoubtedly thrive on a high water table, making pasture for livestock. This would be impaired by the lowering of the water table that would result from the development of a sump drain to convey the water from the sump to the Rio Grande.

The following paragraphs discuss specific conditions affecting use of water under specified systems operating in San Luis Valley.

Rio Grande Above South Fork

The irrigated lands largely comprise hay meadows, with heavy gross diversions and liberal return flow to the parent stream. The largest of these areas lies in the site of the proposed Vega-Sylvestre Reservoir. Construction of this storage would effect a change from hay use to the evaporation from a reservoir surface.

South Fork to Del Norte

Diversions from both banks of Rio Grande and from right bank of South Fork irrigate crops more diversified than those in the higher valleys above Wagon Wheel Gap. Conditions are conducive to return flow to Rio Grande proper for reuse below. The Del Norte Irrigation District owns the Continental Reservoir of some 32,000 acre-feet capacity.

Near Del Norte

Within a few miles of this town are the headings of Rio Grande and Farmers' Union Canals and Prairie Ditch, which convey water across the gentle ridge into the closed basin to the north and east.

Monte Vista Canal

The Monte Vista Canal diverts from the south bank and irrigates lands that may yield return flow to the stream system. This is the high line canal from the Rio Grande. It skirts along the hillside apron to the south until it meets the Terrace Canal flowing northward from Alamosa Creek. The lands commanded lie mostly in a block operated under a water users' association. The Bowen-Carmel area, used for intensive study of water use, is under the lower part of this canal. The tabulation in the Geological Survey's report of its 1936 investigation gives the discharge at three locations which are depicted on the San Luis Valley map. (Pl. 11.)

The Survey's figures show the depletion in canal water from point to point. This canal is largely dependent on its diverted flow as there is very little irrigated land above it to contribute return water until it crosses Gunbarrel Road. (See U. S. Geological Survey record of current flow.) Likewise, being without storage it must rely on its quota in terms of priority and decreed right. Thus the 1936 record may be considered as applying to a conservative diversion duty, there being no sources of supply other than the river diversions except small contributions from Gato (Cat) Creek in times of flood and certain waters from the Terrace Irrigation District along the lower end of the Monte Vista Canal. Some water enters the Bowen-Carmel area from Alamosa Creek through the Scandinavian Ditch. However, there are also some irrigation wells in this area and their number was being materially increased during the summer of 1936 until unusual summer rains assured the potato crop without need of further well drilling. Tail water from this canal finds its way into the irrigated lands served by waters from Alamosa Creek.

Empire Commonwealth Canal

The heading for this canal lies about 2 miles east of Monte Vista. It is the largest canal in the southwest area and third only in the Valley. It lies in Rio Grande, Alamosa, and Conejos Counties. Because the lands are below the area irrigated from Monte Vista and smaller systems, it is reasonable to assume that there is a material but unknown inflow as surface tailwater and as underground seepage from those systems. Thus the diversions probably fall short of the actual water inflow to the lands commanded by the main canal.

Likewise the use of water on the lands irrigated by the Empire Canal in Conejos County, isolated from the main block under this canal, is complicated by surface and underflow from Alamosa and La Jara Creeks and Conejos River. Thus it appears that the diversion figures can hardly be assumed as indicative of the gross duty under this canal.

Conejos River, Alamosa and La Jara Creeks and Tributaries

No large systems divert from these streams, but there is a storage reservoir on La Jara Creek and Terrace Irrigation District stores flood waters on Alamosa Creek. Otherwise the lands are irrigated by direct diversion of their quotas, based on their priorities and decreed rights. The many small diversions can hardly be used as criteria of diversion duties as they command relatively small areas in themselves and their waters are more or less mixed. (One exception to this is the area under Cove Lake Reservoir, a small system storing flood waters from Conejos and San Antonio Rivers.)

Closed Area Diversions

Most of the irrigated land north of the Rio Grande between Del Norte and Alamosa and north of the railroad from Alamosa to the county line between Alamosa and Costilla Counties, absorbs large amounts of water from the Rio Grande as well as all its own local drainage. The bulk of the irrigated land lies under the Rio Grande, Farmers' Union, San Luis Valley canals and Prairie ditch. Geological Survey tables show that the diversions from the Rio Grande Canal exceed the combined diversions from the Monte Vista and Empire canals, and the other diversions by main canals into the closed area are of the same order of magnitude as the largest diversions to the south.

Rio Grande Canal

This old and capacious main canal has a relatively early priority for 383 second-feet with total decreed rights of some 1,700 second-feet, thus exceeding the combined rights of the six largest canals diverting to the south of the Rio Grande and from which a reasonable return flow can be expected. It is also supplied by the Santa Maria Reservoir of some 48,000 acre-feet

capacity. Therefore this canal is well equipped to divert relatively large flows completely away from all connection with the main basin of the river. A relatively small final return of this water is effected by the Rio Grande drain. So far as concerns the basin below the diversion dam of the Rio Grande Canal, the diverted water becomes the net water depletion, except for the minor influence of the Rio Grande drain. Such a return would be further increased by the construction of the sump drain.

For much of its course this is the high line canal on the north side of the river and is not subject to contribution of tail and return water. However, many artesian wells augment the river water, and the lands toward the northern end of the canal may receive flood and other contributions of flow from Carnero and La Garita Creeks. This canal extends to a junction with the channel of Saguache Creek. However, but little flow gets beyond township 42 north.

Farmers' Union Canal

This system diverts water a few miles below Del Norte from the north bank of Rio Grande. All its water is used in the closed area, after being conveyed across lands irrigated from the Rio Grande Canal. There is no return flow to the main river system. The diversions from Rio Grande are augmented by tail waters from higher canals. There are also many artesian wells. Most of the lands irrigated lie in the San Luis Valley Irrigation District.

This system shares water from Rio Grande Reservoir, of 51,000 acre-feet capacity, as well as having a right to direct flow from the river. Tail water and developed drainage can be used in the district served by the Farmers' Union Canal or pass out into the sump around San Luis Lakes.

San Luis Valley Canal

This canal diverts from the north bank of the Rio Grand due east of Monte Vista. It irrigates some land subject to return flow into the Rio Grande but the bulk of its water is conveyed directly into the closed basin and irrigates three scattered blocks of land comprising the Mosca Irrigation District. Between the two southerly blocks is a stretch of land covered by the Prairie ditch and between the two northerly blocks lies a belt in the San Luis Valley Irrigation District under the Farmers' Union canal. Like the latter system, San Luis Valley canal commands an area subject to inflow from adjoining irrigated lands while its tail and drainage water pass out into the sump area around San Luis Lakes. The irrigation district owns Beaver Creek Reservoir, of 4,434 acre-feet capacity.

Prairie Ditch

This canal diverts from the north bank of the Rio Grande a few miles east of Del Norte and flows due east out of the area draining back into the Rio Grande, thence through land watered from laterals of the Farmers' Union canal into a tract entirely surrounded by other irrigated areas, except for a short length on the east end which is open to the sump mentioned above. It can divert some additional water from Rio Grande drain.

Middle Valley

With Indian and Spanish-American peoples irrigating the same lands for many centuries, water usages have become so firmly established as not readily to yield to modern conceptions of water requirements. Fortunately, in New Mexico much of this type of irrigation is confined to the several mountain valleys on Rio Chama, Rio Puerco, and the Jemez River entering Rio Grande from the west and those on small tributaries entering from the east as far south as Santa Fe Creek. In general, usage in these valleys causes heavy return flow. Likewise, below the Puerco on the west are several small tributaries with narrow ribbons of irrigated land along their banks. These are important locally but not in relation to the total irrigated areas in the basin. None of the diversions from the streams mentioned could be classed as for a major canal. The only areas above San Marcial that could be so considered are in the Middle Rio Grande Conservancy District. (Pls. 13-16, incl.)

Irrigation in the basin of Rio Grande in New Mexico can be considered in two major groups, the mountain valleys above mentioned and two main blocks along the Rio Grande above and below Elephant Butte Reservoir.

The following major diversions above San Marcial serve the various divisions of Middle Rio Grande Conservancy District.

Cochiti Division

Canals for this division divert water from Rio Grande below White Rock Canyon, Sili Main Canal from the right bank just about the diversion dam, and Cochiti East Side Main from the left side. Nearly all the irrigated land lies in Indian pueblo grants. Inflow measured to the canals is sometimes augmented by heavy run-off from the side channels that flow intermittently during the summer months. Excess irrigation and groundwaters are accumulated by riverside drains on the east side and to a slight extent on the west side. This developed water is returned to the river and is available for diversion below. The diversion figure for this division may be taken as gross diversions attributable to Indian irrigation methods, modified by the inflow and drainage-canal influence mentioned above.

The lower end of the Cochiti Division is just above Angostura Dam, which diverts water for the Albuquerque Division.

Albuquerque Division

From Angostura Dam to Albuquerque most of the irrigated land lies on the east side of the river under Albuquerque Main Canal. To cover a minor area west of the river a short distance above Albuquerque, the Corrales Main conveys water across Rio Grande. Opposite Albuquerque the river makes an abrupt bend to the east, below which land on the west side is served by the Arenal Canal, diverting at Atrisco Heading, due west of Albuquerque. On the east side the irrigated area gradually pinches out as Isleta Dam is approached. Above Albuquerque the Albuquerque Main has tapered down until secondary canals only reach the city, but the Riverside drain has acquired Main canal proportions and its water is used to irrigate the land on the east side between Albuquerque and Isleta Dam by means of the Barr Canal, diverting from the drain opposite the south end of the city. Diversions to this division are not complicated by much inflow from side drainage. Riverside drains take away excess water from both sides of the river. Since these parallel the river closely, being separated from it by levees only, the measurements of outflow from them are of doubtful significance, as it would appear that the difference in stage of water in the river and in the drainage canals would have great influence on the amount of water carried by the drains and make its source uncertain. For the east side lands below Albuquerque the upper drainage water has likewise become the main source of supply. However, with these conditions understood, the diversions listed for the Albuquerque Main Canal can be taken as indicative of gross or diversion duty for lands that, to a marked degree, have been farmed under irrigation for many years. The lower end of Albuquerque Division is at Isleta Dam, the upper end of the Belen Division.

Belen Division

Just below the Albuquerque Division is the Belen Division. This heads near the Indian village of Isleta, founding of which antedated the conquest. Isleta Diversion Dam serves the Peralta Main (a new canal) and the Chical lateral, Chical acequia, and Cacique acequia, combined diversions from which must be considered as irrigating the land on the east side down to a point opposite Belen. This area is discussed elsewhere (page 365), being one of the intensive-study plats of the Bureau of Agricultural Engineering. (Fig. 83.). On the west side of the river a large new canal, the Belen high line, commands much old land and also an extensive area immediately below it which is not yet under cultivation As in Albuquerque Division, the surplus waters are fed by interior drains into riverside drains. On the east side, Tome drain returns its water to Rio Grande through the Riverside drain, at a point approximately opposite Belen. On the upper west side the Belen riverside drain empties into the river at the Santa Fe Railroad bridge near Belen. Immediately below this bridge, on the west side, the Sabinal drain begins and finally discharges into Rio Grande just after crossing the line between Valencia and Socorro Counties.

The irrigated land on the east side, after pinching out opposite Belen, expands again during the last 3 or 4 miles in Valencia County. This area is served by the San Juan Canal, the head structure of which diverts without a river weir.

Throughout the portion of this division in Socorro County the irrigated land is protected by riverside drains, which collect water and return it to the river without any diversions being made from them for irrigation purposes.

Diversion and consumptive use of water in this division can best be studied from the records for the intensive area, referred to elsewhere. The other parts of the division are badly complicated by the many breaks in the system.

For the last 6 or 7 miles the bottom land is gradually pinched in by low mesas, finally opening up at San Acacia Dam, the upper end of Socorro Division.

Socorro Division

This is the lowest block in the Middle Rio Grande Conservancy District. The irrigated land lies wholly on the west side and is served at the upper end by water diverted at San Acacia Dam by the Socorro Main Canal North. This canal gradually approaches the Rio Grande and merges into the Socorro main center which skirts the Riverside drain, protecting the upper end of this division. It finally unites with this drain just before a secondary structure diverts water both from the tail end of the Socorro main and from the drain canal into the Socorro Main Canal South, which tails out into the Bosque del Apache Grant, lying just below the Middle Rio Grande Conservancy District. Since it has only one diversion from the river and is little affected by side drainage except that resulting from summer cloudbursts, this division probably provides good indications of diversion duty under New Mexico conditions.

Bosque del Apache Grant and River Bottom Land to San Marcial

Immediately below the Rio Grande Conservancy District lies the Bosque del Apache Grant, ending some

5 or 6 miles upstream from the old town of San Marcial. There is now practically no irrigation on the Bosque Grant, although a few irrigation ditches are shown and water rights for these are claimed. The bottom land is under consideration for use as a duck preserve by the United States Biological Survey. There now are no important diversions in this area. Since the construction of Elephant Butte Reservoir, upper end of which lies just below San Marcial, the river bed has been built up considerably by silt deposits. The flood of 1927 practically ruined the town of San Marcial and it has been largely abandoned.

Lower Valley

Palomas Valley

There are no diversions of moment in this area which extends from near Hot Springs, a few miles below Elephant Butte Dam, to the Percha Dam of the Rio Grande project. This valley will be largely submerged by the Caballo Reservoir, now under construction. The high water line for this reservoir is shown on the map of Palomas Valley (pl. 18).

Rincon Valley

This valley lies between the Percha Diversion Dam and the beginning of Selden Canyon. It is the upper end of the irrigated land under the Rio Grande project. This valley is a succession of narrow ribbons of irrigated land, alternating on the two sides of the river. Starting from the right bank, the Arrey Canal diverts water released from storage in Elephant Butte Reservoir and provides a strip 3 or 4 miles long, then is flumed across Rio Grande to merge into the Garfield Canal. From this main, land is irrigated on the left side of the river until Hatch Siphon is reached, where the canal is carried under the Rio Grande to emerge on the right bank again as the Hatch Canal. Water from this canal irrigates all the land on the right bank until the bottom land pinches out on that side. Part way down, the main canal has again been siphoned under the Rio Grande and comes out as the Rincon Canal, extending to the upper end of Selden Canyon.

The amount of the diversions to the main canal at Percha Dam should be fairly indicative of the gross diversion duty for this valley. The canal diversions can be adjusted by taking into consideration water returned to the river and drainage recovery at the outlets of Garfield, Hatch, and Rincon drains. None of the drainage water is taken into the main canal directly.

Mesilla Valley

This valley comprises two parts of the Rio Grande project, the Leasburg Division and the Mesilla Division. They have independent diversions and are discussed below as though they were two major systems.

The first-named extends from Leasburg Diversion Dam at the lower end of Selden Canyon, to cover the land above the two main canals diverting at Mesilla Dam, on either side of the river.

Leasburg Main Canal, covering the Leasburg Division, diverts and remains on the east side of the Rio Grande, with water for certain lands on the west side of the river being flumed across the Rio Grande in the Picacho Canal a few miles northwest of Las Cruces. The diversions into the Leasburg Canal are indicative of the diversion duty for the Leasburg Division, if the amounts of water tailing into the Mesilla Division east side main can be determined. For certain studies, these amounts can be modified by the water returned to the river or discharged into the east side canal of the Mesilla Division and drainage recovery measured at the outlets of Selden, Picacho, and a portion of the Mesilla and Del Rio drains.

It is difficult, if not impossible, entirely to segregate the water at the disposal of the Mesilla Division from that for the Leasburg Division above it. In addition to water diverted and measured at the two canals on right and left ends of the Mesilla Diversion Dam, tail water enters the east side main from various laterals of the Leasburg Division. The west side system is not complicated in this way; its one diversion (the west side main) irrigates all the land on the west side of the Rio Grande from the Mesilla Dam to the place where the irrigated land pinches out on the right bank, as well as a small area on the left bank between Canutillo, Tex., and El Paso by means of a siphon under the river below Canutillo. All the Mesilla Valley in Texas, together with its irrigation and drainage system, are included in the area organized as the El Paso County Water Improvement District No. 1, described below.

As shown on the map, the irrigation system in this valley is completely intermingled with the drainage system. In the Mesilla division there are several returns to the river and drainage recovery is measured at the outlets of Del Rio, La Mesa, East, and Montoya drains.

Mesilla Valley was the southerly intensive area tract studied by the Bureau of Agricultural Engineering for determination of consumptive use, and the details of the relationship of diversions to the irrigated lands are set out elsewhere in this report (pp. 379 to 381 and fig. 89).

El Paso Valley

This Valley comprises the portion of the Rio Grande project below El Paso. Above the pass this district is watered by Mesilla Division canals. Two major canels lead out from the Mexican Dam near the upper end of the city, Acequia Madre diverting on the Mexican side and the Franklin Canal serving the upper end of El Paso

Valley in Texas. A few miles below El Paso the Franklin Canal is reinforced with water diverted from the river at riverside heading, in the newly canalized river.

The distance from El Paso to Fort Quitman, Tex., by the meanders of the old river was some 155 miles. The flat gradient and the lack of flushing floods (attributable to storage in Elephant Butte Reservoir) built up the river bed with sand and silt, and caused an excessive flow of sand into the canals and obstructed the outlets of the drains by raising the river plane onto which they must discharge.

Rectification of the Rio Grande, now in progress, will shorten the distance to Fort Quitman to 88 miles. This will increase the gradient and thus the velocity of the river's flow. The first year in which the upper end of the straightened river was operative (1935) a local flood, originating below Elephant Butte Dam, caused an excessive flow in the lower river and gave a good start to the desired recession of grade in the sandy bed. Rectification of the river is expected to have great influence in the future on the outlets of the drains, as well as several other beneficial effects. The new international boundary follows the thread of the rectified channel. However, rectification of the channel is not complete and part of its projected course has not been definitely decided upon.

As the Valley approaches San Elizario Island, the island main takes off from Franklin Canal and crosses the old channel of Rio Grande in island flume. This canal quickly tapers down to a small lateral and water for "the island" is reinforced by two diversions in the old channel at Hansen heading. After the island canal leaves the Franklin main, the latter rapidly tapers as the irrigated land temporarily pinches out on the left bank at Fabens. Just below this point the Tornillo heading serves Tornillo Canal for the rest of the way on the left bank of Rio Grande to the lower end of the Rio Grande project.

All the diversions to these canals are measured and are indicative of the gross diversion duty in this valley. In order to ascertain the net use, it is necessary to deduct the waters returned to the Rio Grande and the drainage recovery from the main drains to which the irrigated lands contribute. Coming down the river from El Paso, the return water carried in the drainage canals is measured above Fabens. The situation may be made more complex by the influence of the irrigated land in Mexico.

The drainage water developed on "the island" is siphoned across the old river channel just above the location of the rectified channel as now (1936) projected but not yet constructed. This water joins the Tornillo drain, which later meets the Alamo Alto drain, located along the hillside edge of the valley from Fabens downstream. The combined drainage water return to Rio Grande at the lower end of the project is measured just above the outlet. Likewise, tail water at the lower end of Tornillo Canal is measured as it is delivered to the Hudspeth Canal or is discharged into the Rio Grande below the drainage outlet just mentioned. These three points of measurement are a short distance above the line between El Paso and Hudspeth Counties.

Hudspeth County Conservation and Reclamation District No. 1

The drain and tail water from the El Paso Valley system becomes the irrigation supply for most of the remaining valley lands above Fort Quitman. The Hudspeth County Main Canal extends throughout the length of the district system, and its diversion, as measured at the heading just above the line between El Paso and Hudspeth Counties, plus the Alamo Canal, may be taken as the gross diversion duty for this area. The Alamo diverts directly from the Rio Grande about 3 miles west of Fort Hancock. The Hudspeth County district is developing a drainage system.

Summation of Diversions and Areas

The irrigated areas for the entire Rio Grande Basin above Fort Quitman, with the adjacent areas in native vegetation, are summed up in table 122 by main canals or systems. In appropriate columns, the total amounts of water diverted are shown. The latter are compiled from measurements and computations by the Geological Survey, Division of Surface Waters, which are being published in Water Supply Paper No. 839. These amounts may be taken as generally indicative of the diversion or gross duty of water for the areas tabulated, but for many areas in San Luis Valley, intensive investigation would disclose necessary modification of the diversion figures because some of water comes to them at unknown times, and in unknown quantities, from adjoining canals or areas of land. Likewise, some of the water listed as diverted occasionally is not used on the land usually served, but may be used on areas other than those listed as subject to the diversion. Ascertainment of the inflow to many areas is likewise made complex, in undetermined amounts, by the unrestricted flow of several thousand artesian wells. However, the tabulated data furnish criteria applicable to other areas where the detailed diversions were not measured or where, because of the mixing of waters or areas, the irrigated lands could not be segregated in accordance with their appurtenant canals and ditches.

The aggregate areas for the canals in San Luis Valley, shown in table 122, are less than half the Valley's totals, but for New Mexico and Texas the systems are such that the areas listed cover most of the acreage on the main stem of the Rio Grande. In the Middle section the aggregate interior valley acreage is greater than that on the main stem, but complete records do not exist for the corresponding diversions.

Table 122.—Canal [illegible]—Upper Rio Grande Basin, by major canal systems, [illegible]

[illegible]	[illegible] (acres)	Irrigated	[illegible]	[illegible] etc.	Total	Total	[illegible]	[illegible]	[illegible]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Colorado									
[illegible]									
[illegible]	[illegible]	111,844	[illegible]	11	115,516	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	46,267	2,775	397	49,439	45,710	[illegible]	[illegible]	.48
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13,144	10,900	[illegible]	[illegible]	[illegible]
San Luis Valley Canal	40,524	8,234	1,159	14	9,407	21,790	2.64	2.31	.54
[illegible]	[illegible]	24,382	[illegible]	[illegible]	24,772	37,520	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21,731	[illegible]	[illegible]	[illegible]	[illegible]
New Mexico									
Middle Rio Grande Conservancy District (total)	187,682	[illegible]	2,98[illegible]	[illegible]	[illegible]	[illegible]	10.48	[illegible]	3.30
[illegible]	19,439	5,208	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.99	[illegible]
[illegible]	58,127	22,819	[illegible]	4,241	[illegible]	[illegible]	10.29	8.40	4.04
[illegible]	77,044	23,895	[illegible]	[illegible]	25,590	241,993	[illegible]	9.46	3.14
[illegible]	33,072	7,237	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.59	[illegible]
New Mexico-Texas									
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	15,2[illegible]	[illegible]	110	[illegible]	[illegible]	5.16	[illegible]	2.81
[illegible]	110,418	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.03	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.82	[illegible]
[illegible]	21,[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	3.57

[illegible]

PART III
SECTION 6.—THE VEGETATIVE COVER SURVEY

The original plan for mapping the vegetative cover was much simpler than the plan approved in conference at Santa Fe. Essentially, however, the initial purpose that of ascertaining the areas of irrigated land and other land representative of vegetation "using appreciable quantities of water"—was retained. It was finally decided to account, on a map, for 100 percent of the area between the lower fringes of the hills and bluffs along the main stem of Rio Grande through New Mexico and Texas, and to set such limits for the work in Colorado as would keep the map from including areas which could not meet the stipulation of "using appreciable quantities of water."

One object of this part of the Rio Grande study was to furnish an estimate of the total quantity of water completely removed from various parts of the stream basin during the season of 1936. This involved the determination of the consumptive use of the irrigated lands and towns and cities actually given water; the consumptive use of "native vegetation" not given water but taking it by virtue of access to the water table; and the evaporation from river and lake surfaces and moist beds. It was assumed that roadways and railroad grades use little more than nominal quantities of water; a small allowance was set up for such lands to represent evaporation losses.

The following list of classes of vegetative and other areas was adopted for mapping:

1. Cotton.
2. Alfalfa and clover hay.
3. Native grass cut for hay.
4. Irrigated pasture.
5. Early season annual crops (field peas, small grains).
6. Late season annual crops (corn, sorghums, silage fodder, sugar beets, potatoes).
7. Miscellaneous (orchard, vineyard, tobacco, beans, onions, melons, chili peppers, garden truck).
8. Land normally irrigated but temporarily out in 1936 for various reasons.
9. Areas in native vegetation using water in appreciable quantities and river bed or open water.
   - *a.* Open grass.
   - *b.* Brush.
   - *c.* Trees—Bosque.
   - *d.* Open pooled water.
   - *e.* River and canal surfaces and exposed beds.
10. Double cropped areas.
11. Town and village areas.
12. Areas once irrigated but not now (largely San Luis Valley).
13. Bare land.

The original plan to ascertain the irrigable land, both inside and outside the constructed irrigation systems, was revised to cover only those areas within the reach of the systems already constructed and planned minor additions and extensions to them. This curtailment was decided upon in recognition of the fact that there could not be any great quantity of water available for extensions of the irrigation system; that the arable land available would be many times greater than any gross area that could be regarded as feasibly irrigable. Thus the final stipulation holding the mapping of arable lands to the valley floor along Rio Grande in New Mexico and Texas, recognized that reclamation and irrigation of the dense growth of native vegetation areas merely changed the use of water from its natural nonbeneficial use in large quantities to a beneficial use by irrigated crops in appreciably smaller net quantities. In other words, such extension of the irrigated areas as would displace water-loving native vegetation would not increase the use of water by those areas but would, in fact, decrease it and make more water available for general purposes.

After the field mapping there remained the essential task of converting pictured type classifications into acreage and separating that acreage into summations, by counties, major canal systems, major tributary areas, and many other requested segregations. These summations appear in the tabulations which conclude this discussion.

Deductions for Roads, Railroads, Canals, etc.

It was appreciated that all of any irrigated land area is not actually in crop although to all appearances wholly comprised of irrigated lands, so 3 percent was deducted from the gross areas of irrigated lands mapped.

Irrigated land is pictured on the maps as nearly as possible to true scale but was tabulated on the basis of net acreage or 97 percent of the gross area mapped, the other 3 percent being computed by slide rule to the nearest number divisible by 6 and restored to the tabulation as follows: One-sixth to water areas; one-half to bare land areas, and one-third to grass areas. The water areas restoration was assumed to represent the water surfaces of irrigation and drainage channels; the bare land restoration as the traveled strip of roads, railroad roadbed, farm lanes, and other bare areas that consume small amounts of water, such as evaporation after precipitation in areas of high water table. The grass areas restoration accounted for the wide strips

of grass along all roads, between the traveled strip and the fences confining the fields; and the similar strips along railroad tracks, between the roadbed and the right-of-way fence; also, the banks and berms of irrigation and drainage channels.

Native vegetation was also tabulated for net areas, 1 percent being deducted for bare land in terms of roads, lanes, and railroad beds and restored to the total in the bare land classification. No deduction nor restoration was made for the water areas. The deductions and restorations were uniformly applied throughout the basin, in accordance with instructions decided upon at the June conference in Santa Fe.

Practical Operation of The Mapping Plan

Original plans to conduct the mapping simultaneously in the three principal sections of the basin had to be changed because of the lateness of the season in Colorado and New Mexico as compared with that below El Paso. Indeed, although the mappers did not start their work in Hudspeth and El Paso Counties until May 4, their progress was impeded for a time by the fact that, even then, many of the crops had not been planted. However, the predominance of cotton and alfalfa in that part of the Valley, and other favorable circumstances, permitted a concentration of the mapping force in the area. Later, as conditions in the upper divisions permitted, the original mapping force was distributed and increased. Thus it was possible to start the mapping of the New Mexico areas above San Marcial early in June, and the San Luis area a few days later.

The following paragraphs describe the problems encountered by the mappers and how they were met.

In general, "land formerly irrigated" was found mostly in San Luis Valley, at least in terms of areas that may now be identified. In the Middle Valley, areas waterlogged and not farmed under irrigation for long years are being reclaimed by the Middle Rio Grande Conservancy District. In the map of Bosque Del Apache Grant, south of the district, irrigation canals are shown, but although some land was formerly irrigated it cannot now be definitely located, hence is not so tabulated.

[illegible] Luis Valley that the land formerly irrigated could nearly always be definitely located from aerial survey pictures,[1] as these areas [illegible] and brush than that of other areas. Thus mappers may have designated an area as "9b and 12" which meant that the land was now in brush but evidence showed it to have been irrigated at some time in the past. In the tabulation such acreage appears in column headed "9b—brush"; also in the column "land formerly irrigated", but it is not taken into the summation twice. In other words, all the acreage listed as formerly irrigated stands by itself and, having appeared once, is not again added into the totals.

Within any irrigation system not all the irrigable land is farmed under irrigation in any one year. (Careful determinations in California disclosed that such land "temporarily out of cropping" for various reasons runs about 20 percent for highly developed diversified farming regions, and 25 percent for less intensively farmed regions.) This land is not to be confused with "land formerly irrigated." Apparently it was irrigated last year or the year before, and presumably will be irrigated next year or within a few years. It is now lying fallow, is involved in litigation, or is not farmed because the owner simply chooses otherwise for the current year. Such land is usually entitled to irrigation water and must be considered in allocating an "irrigation requirement" to the major area in which it appears.

San Luis Valley

The work in San Luis Valley was handled by three 2-man parties, all under the direction of the Bureau of Agricultural Engineering.

At first much difficulty was encountered in adapting and applying the predetermined classification to the crops and conditions existing in the Valley. While the classification served admirably in the area below the Elephant Butte Dam under the high type farming methods practiced there, it could not be followed so easily when applied to the type of agriculture prevalent throughout much of the San Luis Valley. It was difficult at times to tell whether water was artificially applied or not applied at all but merely expected to be present because of the practice of subirrigation on surrounding plots.

Since there is no cotton in San Luis Valley, the no. 1 classification was not used. Generally no trouble was experienced in identifying alfalfa and clover (no. 2). "Native grasses cut for hay" (no. 3) were, in the early part of the season, often indistinguishable from the next class, no. 4 (irrigated pasture), and sometimes were confused with no. 9 a (open grass). Both the former classes were flooded with water and usually appeared identical. In fact, in many cases, after the hay was cut, stock was turned in and pastured the remainder of the season. The presence of stack butts or hay corrals usually indicated hay, while grazing stock indicated

[1] [illegible] sheets. (See page 409.)

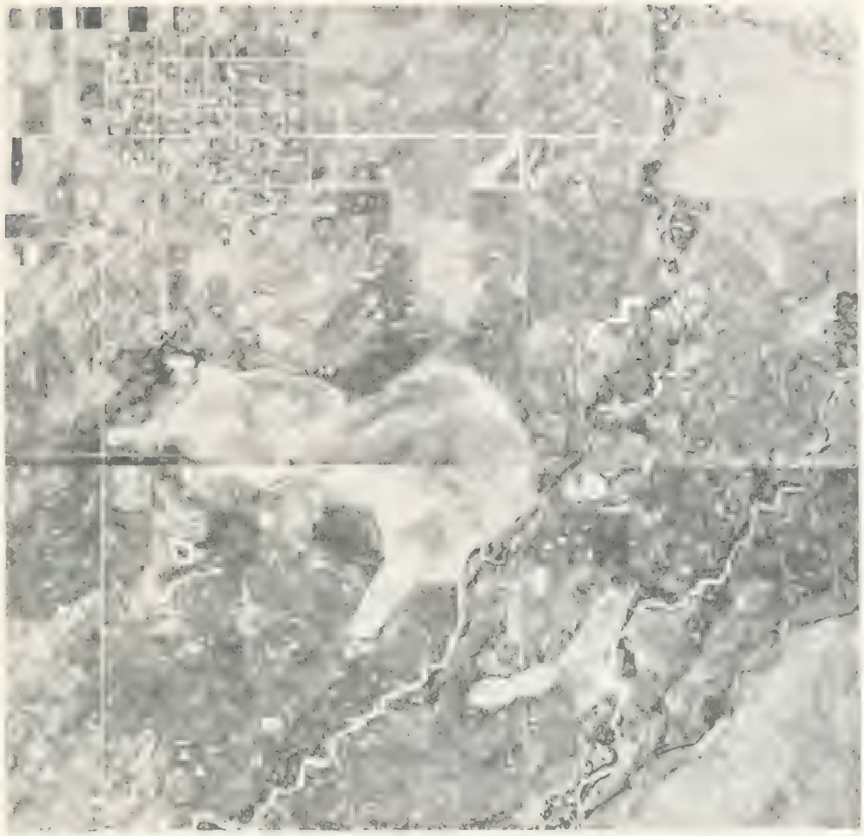


FIGURE 96.—Aerial view of area southeast of Manassa, Colo. (in upper left here) [illegible], illustrating complexities of mapping problems. For instance, extreme upper left shows nicely squared fields, easily mapped, with offset roads clearly pictured. East of Manassa is the race track, then an alfalfa field [illegible] white border around a dark patch. South and east of Manassa the fields blend into large areas of stream-bottom lands without means of identifying portions of sections. In the center is noted a large hill without appreciable vegetation cover.

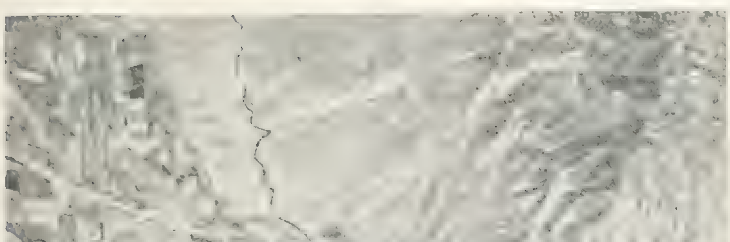


FIGURE 97.—Aerial view of old Mexican irrigated area in San Luis Valley, Colo., near town of San Luis, illustrating ribbonlike shapes of the small farms. The dark areas near the bottom are clouds between the airplane and the ground, showing the need for clear days in aerial photography. Note that canals are dark and sandy roads are white. Extremely dark fields are usually alfalfa. Two streams enter the picture from the right. The irrigated lands, commanded by high-line canals, are definitely located on such a picture. The large canals with arrows divert in two directions and irrigate distant lands not shown on this view.

cutting. Where neither was in evidence the decision as to proper classification rested on the judgment of the mapper and was based on the moistness of the land, the apparent practice in the neighborhood, and occasionally only on guess. When the season was farther advanced, the presence of workmen in the hay fields and the new stacks removed any doubt. Patches of brush often appeared on high spots in meadow land. If large, they were sketched in and called such, but if small and scattered, they were ignored.

Application of the no. 5 classification (early season annual crops) was complicated by the practice of combining several crops for the purpose of feeding stock. This practice consisted in drilling a mixture of field peas and oats, barley, or other small grain into a field of volunteer or seeded clover. The resulting crop, its various parts distinguishable only on close inspection, often appeared to contain but one of them, and might be often mistaken for a field of either clover or grain. The classification was further complicated by the great mass of sunflowers often found in fields of the Valley. During the course of the summer, this combination might be either pastured or "hogged down" by herds of cattle or sheep, or if not fed thus during the summer, it might be cut with mowing machines and stacked as hay. After consideration as to whether this crop came under the classification of clover (no. 2) or, because of its use, might better be called a late season annual or silage crop (no. 6), it was finally classified as being mostly field peas and grain (no. 5).

Probably the only difficulty experienced with the no. 6, or late season annual group, was during the early part of the season before planting was finished. At that time fields were being plowed and leveled, and sometimes irrigated before being planted, but this procedure usually indicated one of the crops in this group, and the field was classified according to the indication.

The largest part of the no. 7 class was garden truck and garden peas. The latter were usually distinguished from field peas by being cultivated in rows. Occasionally a garden had been harvested before the area was classified, leaving only a patch of sunflowers. It was hard to tell whether it was this year's field or one remaining fallow from the year before. If other indications were not present, it sometimes became necessary to make inquiries. Where these patches had been plowed up and leveled they were sometimes confused with alfalfa, which may be plowed under at any time during the year. These cases were few, however, and if on closer inspection, evidence was not found to show which had been planted, inquiry was made at the farmhouse.

No. 8 (land normally irrigated but temporarily out of cropping in 1936) was occasionally confused with no. 12 (land formerly irrigated but not in recent years). It was often impossible to tell how long the land had been out of cultivation. If it were freshly plowed, or furrows and raw earth were in evidence from the last year's cropping, its classification was easy; but if a thick growth of weeds covered the area it was not so readily identified. In this case, since the weeds indicated it had not been "out" for more than 2 or 3 years at the most, the benefit of the doubt was given to late cropping and classification no. 8 was applied. The condition of adjoining farm buildings and whether or not they were inhabited also influenced the decision. Because of shortage of water in the Valley, only rarely were any fields found being leached for reduction of alkali.

Very little that could strictly be called open grass (no. 9 a) was found. There was some along stream and overflow channels and between the waterline and brushline around lakes and ponds. Large areas readily identifiable as brush were often found in heavily alkalized areas, but grass and brush were mostly found together and were practically impossible to separate. This was especially true in the sump area, where the entire surface was a series of humps and hollows. Several humps or mounds of wind-drifted sand 15 to 100 feet across and 5 to 15 feet high, covered with greasewood brush, usually surrounded a hollow or depression. In the depression or pot hole a band of grass and a band of mud or alkali flat would encircle a pool of water. The pool might have remained there since the last rain, or it might be fed by a nearby artesian well. It might also be completely dry, its bottom covered with grass or alkali.

Using aerial photos of the area, the mappers traveled along the numerous trails, identifying their position by the features shown on the map. The pools of water were marked as such if large enough to be identifiable; also the large tracts of grass if extensive enough. The remainder, including all areas too small to be separated and the large areas consisting of a mixture of both brush and grass, was lumped together and called brush and grass.

Trees were definitely identifiable and were so noted when in large enough groups to show on the map.

No double cropped areas were found in the Valley; hence, class 10 was not used. Towns and villages were outlined as closely as possible and classed as no. 11.

Classification no. 12 (land formerly irrigated but not in recent years) gave some trouble, being confused with both classification no. 8 (land temporarily "out") and no. 9 (native vegetation). In many cases, because of the practice of subirrigation, the land possibly had raised crops for many years with no surface irrigation whatever. It had later become seeped and alkalized as a result of irrigation above it, and consequently abandoned, thereupon reverting to brush and grass. Often the reversion was so complete as to defy distinc-

tion from adjacent areas of virgin soil. In such cases the presence of old irrigation ditches and borders, or the difference in elevation of what might have been the tilled field and the undisturbed border of the field, caused by wind erosion of the plowed part, and other such indications, were taken as evidence of former irrigation. If such evidences were lacking, the word of residents was taken or the condition of the surrounding areas was used as an index.

The question of a limiting line or upper boundary of the mapping often arose. At first it was thought that everything below 8,000 feet elevation would be mapped. It was found, however, that this practice could not always be followed. Rivers and canyons were followed up as far as there was any appreciable amount of crop land. Where the floor of the Valley ended at the foot of the mountain slope, the mapping was carried up to any high-line ditch or to include the flattest part of the land, which might possibly later be placed under irrigation. Where hills rose from the floor of the Valley, crops and abandoned crop lands were mapped as they appeared, native vegetation was mapped on the flatter slopes and the steep slopes and hill tops were marked as high land, above irrigation. On topographic sheets the work was sometimes carried up to a certain contour, but usually the limit lines were sketched in by eye between already established points. In this manner some land was included which was later eliminated in the transposition to the air photographs.

For instance, in an area of native vegetation, the limit on a mountainside was originally established by estimate and a general line was drawn. On the air photographs the changing slope and the condition of the vegetation usually indicated a far more distinct and better located line than the original, and the limit was then so altered as to conform to the air photographs.

On completion of the actual field work, part of the map was on sheets of various kinds, the remainder on the air photographs. The latter portion included large blocks for which the air pictures became available before work was done in the area by other means, the strips originally left along major streams, and scattered patches of several sections each, which had to be left from time to time because they were too difficult to traverse.

While considering means of arranging these various work sheets into a comprehensive map which could be easily handled during the subsequent office work, it was suggested that all the work be transposed to the air photographs, all of which were then available. Such transposition would necessarily have to be made sooner or later as the details in the final report would be based upon the aerial survey which, as had been discovered, occasionally differed somewhat from the original mapping. In the original work it had often been necessary to idealize some fields and lump others together. On the air maps it was generally possible to differentiate the various plots more clearly. It was thought that the work of transposition could therefore be best done by those familiar with the conditions. The results depicted would then be uniform over the entire San Luis Valley, and would compare favorably with those obtained in New Mexico and Texas.

This was decided upon as the best way to complete the work. The small aerial work sheets were pasted together into several large blocks each about 3 feet wide by 4 feet long. By comparison with the original field sheets, each plot was then identified and classified, corrections in size and shape being made where necessary.

Middle Valley

The field mapping of the West Side tributaries (including those south of San Marcial) was done by the Resettlement Administration under the immediate direction of Ralph Charles, land planning specialist, of Albuquerque. The areas along the main stem of the Rio Grande, largely comprising the Middle Rio Grande Conservancy District and most of the East Side tributaries, were covered by the Bureau of Agricultural Engineering's field party. During the final 6 weeks of the field work, a party of five men from the forces of both the Bureau of Agricultural Engineering and Resettlement Administration, covered the remaining areas in Espanola Valley and along the small streams entering the Valley from the east.

Field maps.—Throughout this region the field mapping was done on prints resulting from an aerial photographic survey of the Rio Grande Basin in New Mexico, north of the Thirty-third parallel, for the Soil Conservation Service. The flying for this survey was done by a western corporation during the 1935 season, but most of the fields were easily located on the prints, and identification of the crops according to the 1936 classification plan involved no general difficulty. Without these aerial photographs the field work would have been greatly increased because the farm descriptions do not conform to Federal land survey units. The present farms originally may have comprised large blocks of land, but in willing their property to their descendants, successive owners subdivided the places into as many pieces as there were heirs, each piece being so shaped as to have contact with the irrigation ditch and the road. This process, continued through many decades, resulted in irregularly shaped ribbons of land sometimes as narrow as 5 or 6 feet, but sometimes as long as a mile or even more. Accurate mapping of the crops on such farms was tedious and frequently difficult.

However, boundary lines were clear-cut, as was the case below Elephant Butte Dam. The leader of one

[illegible]

of the parties had trained for work in the latter area, and applied the same criteria that had been adopted there.

Scale of maps.—The scale of 2 inches to the mile, decided upon for the drafting of all the maps, was found to be infeasible for field-mapping parts of the Middle Valley, chiefly because of the peculiarity just described. Therefore, where the major areas were badly congested the photostats were made on a scale approximating 4 inches to the mile, or twice the original scale. On this scale a square 40-acre tract is 1 inch on the side; hence it permitted locating and proper classification of fields as small as 1 or 2 acres. The tabulation of areas was based on the field designations, even for very small patches. However, on the map intended for final reproduction, many of the smaller areas could not be marked with a class-symbol and had to be grouped together under a miscellaneous classification. Thus all areas along the tributaries in New Mexico and the main river from Embudo to Belen were field-mapped on the 4-inch scale. The southern portions of the areas along the river were mapped on the 2-inch scale.

Lower Valley

Although the Lower Valley served in a way as a training school for the mapping parties because the program was initiated in this area, the difficulties encountered were fewer than those occurring in the other sections. Favorable weather throughout May and June, coupled with a liberal assortment of good roads and the fact that the automobiles used were in serviceable condition, favored rapid coverage of the country. Equally favorable were the geographic circumstances characterizing a narrow and definitely bounded valley and the fact that clear aerial maps of recent date were available from the beginning of the work. These were in mosaics on the 2-inch to the mile scale except for the section between San Marcial and the thirty-third parallel, for which only contact prints were available. While these latter needed scale-

correction before being worked into the finished map, they involved only a small area of agricultural lands, and their use caused no delay in the field work.

The mosaics were made available by the International Boundary Commission; the contact prints by the Soil Conservation Service. Also used in orienting the mapping parties and guiding the office draftsmen were various maps based upon accurate instrumental surveys by the International Boundary Commission and the Bureau of Reclamation. These maps likewise were of great assistance in forwarding all stages of the work.

The mosaics showed the survey course of the river below El Paso projected as well as partly constructed by the International Boundary Commission. As planned, the rectification would affect certain lands in bends of the unrectified channel by transferring some areas formerly in the United States to Mexico, and vice versa. To facilitate its program, the commission had acquired title to such lands, and pending completion of its project, had removed most of them from agricultural use. Such of these areas as were north of the new channel were mapped as in native vegetation or "temporarily out of cropping" according to their more prominent characteristics, if in fact they were either not actually farmed or were incapable of being farmed for various reasons.

The mapping parties were instructed to show on their maps all land from the foot of the bluffs north of the river to the new channel where the latter actually existed, and to the north bank of the river in those stretches where the projected canalization had not yet been effected. An important exception was made in the case of the "island" section below Ysleta, where a large intensively farmed area of Texas land lies south of the river, although north of the channel existent when the original international boundary was established. Adjustment of the boundary (in terms of the rectified channel) affecting this so-called island has still to be made; the map was therefore carried to the fringe of trees and other native vegetation which marks with approximate clarity the course of the old channel.

Similarly, since the construction of Caballo Reservoir, now under way, had not started when the mapping parties were at work, the area presently to be submerged by its storage was mapped in accordance with the scheme of classification applying to other areas, and so appears on the finished map. (Pl. 18.)

The principal handicap to accurate field work in the Lower Valley was the fact that planting had not been finished when the mapping was started, nor was it entirely finished for several weeks afterward. Similarly, the planted crops on many farms had not yet come up and could not be identified with assurance. Still further probably affecting the accuracy of the map for this area was the uncertainty as to what cropping changes would be made under the operation of the Soil Conservation Act as successor of the Agricultural Adjustment Act. To a considerable degree, therefore, the mapping of this area was unavoidably based upon anticipated rather than realized plantings. Because cotton and alfalfa together represent the greater part of the cropped area, this complication resulted especially in the mapping of larger acreages of cotton and new alfalfa than those later harvested. While the field parties sought to resolve frequent doubts as to the crops by interviewing the farmers operating the areas in question, it was not always possible to do this without delaying the work unjustifiably; reliance was then upon their best judgment as guided by such indications as stalks remaining from the crop last planted or field preparations suggestive of the crops later to be grown.

These were doubtful guides in both El Paso and Mesilla Valleys because they applied to many areas included in the extensive cotton-reduction programs of 1935 and preceding seasons, which actually were not returned to cotton notwithstanding early indications that such return was planned for 1936. (See footnotes and accompanying discussion of table 15, p. 313.) Instead, many such areas are now known to have remained out of production entirely or to have been planted to other crops.

	Total area	Irrigated area	Cotton area	Alfalfa area
Rincon Valley:				
Bureau of Reclamation........acres..	26,621	13,528	5,504	2,800
Bureau of Agricultural Engineering. acres.	27,914	15,206	6,646	3,231
Difference........acres..	1,293	1,678	1,142	[illegible]
Do........percent..	[illegible]	12	21	15
Mesilla Valley, N. Mex.:				
Bureau of Reclamation........acres.	95,297	64,915	39,009	12,678
Bureau of Agricultural Engineering acres.	[illegible]	72,258	[illegible]	[illegible]
Difference........acres.	1,283	7,343	8,496	2,062
Do........percent.	1	11	22	16
Mesilla Valley, N. Mex., and Tex.:				
Bureau of Reclamation........acres.	109,123	74,813	[illegible]	14,822
Bureau of Agricultural Engineering acres.	110,418	[illegible]	54,513	17,077
Difference........acres.	1,295	8,110	9,247	[illegible]
Do........percent	1	11	20	15
Mesilla Valley, Tex.:				
Bureau of Reclamation........acres..	13,826	9,898	6,257	2,144
Bureau of Agricultural Engineering acres	13,838	10,665	7,008	2,337
Difference........acres	12	767	751	193
Do........percent	[illegible]	8	12	9
El Paso Valley:				
Bureau of Reclamation........acres..	71,478	50,460	30,575	12,678
Bureau of Agricultural Engineering acres..	72,838	[illegible]	37,493	14,312
Difference........acres..	1,360	5,963	6,918	1,634
Do........percent..	2	12	23	13
Elephant Butte district:				
Bureau of Reclamation........acres..	[illegible]	78,443	44,513	15,478
Bureau of Agricultural Engineering acres..	124,494	87,464	54,151	17,791
Difference........acres..	2,576	9,021	9,638	2,493
Do........percent.	2	[illegible]	[illegible]	16
El Paso County water improvement district no. 1:				
Bureau of Reclamation........acres..	85,304	60,358	36,832	14,822
Bureau of Agricultural Engineering acres..	[illegible]	67,088	44,501	16,649
Difference........acres..	1,371	6,730	7,669	1,827
Do........Percent..	2	11	21	[illegible]
Rio Grande project:				
Bureau of Reclamation........acres..	207,222	138,801	81,345	30,300
Bureau of Agricultural Engineering acres..	211,170	154,552	98,652	34,620
Difference........acres..	3,948	15,751	17,307	4,320
Do........percent..	2	11	21	14

Mapped areas and corresponding acreages reported in the 1936 crop census of the Rio Grande project are set out above, without corrective adjustment to account for the complications already described and the equally important handicap to accuracy discussed in succeeding paragraphs of this chapter.

Mapping of the entire area below San Marcial was done by the Bureau of Agricultural Engineering, except for the valleys of the small West Side tributaries in New Mexico, which were mapped by the Resettlement Administration. No such tributary areas required mapping on the other side of the river in either New Mexico or Texas. The mapping included no areas in Mexico.

Results of the Mapping

The results of the mapping are summarized in table 123 from details appearing in tables A, B, and C.

The agreement of the mapped acreages of irrigated crops with other 1936 compilations is reasonably close in the case of the Middle Valley areas. (See p. 309)

The mapped areas for San Luis Valley are substantially less than the corresponding acreages reported by the water commissioners. (See table 1.) In this case the discrepancies appear to bear out the conclusions of previous investigators, that the commissioners' figures are generally too high. (See pp. 291 to 302.)

Partly for the reasons already mentioned on page 411 the irrigated crop acreages mapped for the areas between Elephant Butte Dam and Hudspeth County are in excess of those developed by the 1936 routine crop survey conducted by the management of the Rio Grande project and are considered too high by the Bureau of Agricultural Engineering. However, as stated on page 406, a deduction of 3 percent was applied uniformly throughout the basin, to convert the mapped areas of irrigated land, areas temporarily out of cropping, and areas in cities, towns, and villages, into project areas. In the case of the Rio Grande project, which has an excessive number of drains and canals, this deduction should have been increased—perhaps doubled. At the other extreme, the 3 percent deduction was undoubtedly too large for San Luis Valley. It is considered to have been about right for areas along the main stem of Rio Grande in Middle Valley, though too large for the interior valleys.

Since it was the decision of the May conference to apply a percentage deduction uniformly throughout the basin, 3 percent was about as fair a proportion as could have been selected.

For the Lower Valley, while a doubling of the deduction would not account wholly for the discrepancies, consideration of the appropriateness of such an increase and of the complications affecting the field work as set out on page 411, should establish a reasonable degree of harmony between the two compilations. The disagreements are not considered large enough to make practical differences in determinations of consumptive use requirements for the project, especially since many areas temporarily out of cropping may be expected to return to production eventually if the water supply permits.

Map plates

The final vegetative cover maps in separate accompanying this report comprise plates 10 to 22, inclusive. Originally drawn to a scale of 2 inches to the mile, the printed results, in colors, are on a scale of 1 inch to the mile. They cover all areas showing irrigated land along the main stem of upper Rio Grande. In addition to the usual basic features, these maps show the vegetative cover and the stream- and canal-gaging stations that form important parts of this investigation.

Plate 10 "Mountain Valley of Rio Grande" begins at the upper limit of irrigated land as found in the field mapping and extends nearly to Del Norte. The balance of the area in Colorado is shown on the map of "San Luis Valley" (pl. 11, in two sheets, the "north half" and the "south half"). This plate shows, in green, the detailed location of the intensive study areas indicated for Colorado on figures 75 and 78. South of the canyon section in northern New Mexico all of the "plates" form complete units as known in the region. Española Valley (pl. 12) covers lands largely in three Indian Pueblo grants. The four operative divisions of Middle Rio Grande Conservancy District (Cochiti, Albuquerque, Belen, and Socorro) are covered in plates 13 to 16, inclusive. On the "Belen Division" (pl. 15) is shown in green, the detail of the "Isleta-Belen" intensive study area indicated on figures 75 and 83. The "Bosque Del Apache Grant" (pl. 17) extends to the lower end of irrigation at the head of Elephant Butte Reservoir. The base maps for plates 14 to 17, inclusive, are repeated (as pls. 6–9) by the Geological Survey in its depiction, in red overprint, of the ground water conditions in the areas covered. Below Elephant Butte Dam, the irrigated land commences in Palomas Valley (pl. 18). The Rio Grande project of the Bureau of Reclamation is covered in three plates (19 to 21, inclusive), showing Rincon, Mesilla, and El Paso Valleys. Mesilla Valley (pl. 20) was used as a whole for the intensive-area study indicated on figures 75 and 89. The final map of "Hudspeth County" (pl. 22) shows but little irrigation not included in the boundaries of Hudspeth County Conservation and Reclamation District No. 1.

TABLE 123.—*Areas of vegetation and other cover in Upper Rio Grande Basin* [illegible] *tables A, B, C*

[illegible]	Total area mapped	[illegible] Irrigated in 1936	Temporarily out of cropping	Cities, towns, and villages	[illegible] ed, "out" and towns	[illegible] Native vegetation	Water and river bed surfaces	Total non-[illegible]	Bare land, [illegible] rights-of-[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	948, 171	[illegible]	[illegible]	86, 525
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	737, 199	[illegible]	750, 961	70, 440
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	404, 014	4, 010	468, 024	37, 570
[illegible]	[illegible]	[illegible]	10, 104	[illegible]	[illegible]	333, 185	9, 752	342, 937	32, 870
[illegible]	[illegible]	270, 350	7, 228	4, 103	281, 681	176, 191	6, 549	182, 740	18, 110
[illegible]	[illegible]	51, 971	2, 876	892	55, 739	156, 994	[illegible]	160, 197	14, 760
[illegible]	537, 891	242, 684	21, 681	12, 097	276, 462	193, 116	53, 591	246, 707	[illegible]
[illegible]	127, 729	75, 173	4, 534	3, 110	82, 817	31, 622	10, 956	42, 578	2, 331
[illegible]	12, 878	5, 891	374	[illegible]	[illegible]	3, 651	2, 336	5, 987	[illegible]
[illegible]	49, 011	[illegible]	1, 207	[illegible]	[illegible]	11, 645	5, 973	17, 618	468
[illegible]	65, 840	40, 128	2, 953	[illegible]	[illegible]	16, 326	2, 647	18, 973	[illegible]
[illegible]	221, 786	76, 690	8, 323	[illegible]	[illegible]	[illegible]	25, 532	122, 039	[illegible]
[illegible]	187, 682	59, 159	2, 980	6, 165	[illegible]	[illegible]	21, 895	[illegible]	7, 082
[illegible]	34, 104	17, 531	5, 343	[illegible]	[illegible]	[illegible]	3, 637	9, 743	[illegible]
[illegible]	12, 583					10, 164	1, 970	12, 134	419
[illegible]	4, 811	919	[illegible]		[illegible]	2, 617	907	3, 524	[illegible]
[illegible]	26, 147					22, 071	3, 384	25, 455	692
[illegible]	144, 838	89, 902	[illegible]	1, 846	100, 242	30, 135	10, 842	40, 977	3, 619
[illegible]	[illegible]	830	501	304	1, 635	7, 435	1, 190	8, 625	[illegible]
Elephant Butte Irrigation District	124, 494	87, 464	7, 362	1, 404	[illegible]	[illegible]	6, 251	24, 855	[illegible]
West Side tributaries	[illegible]	1, 608	631	138	2, 377	4, 096	3, 401	[illegible]	87
Texas (total)	108, 271	[illegible]	5, 659	787	[illegible]	17, 856	1, 942	19, 798	1, 360
El Paso County Water Improvement District No. 1	86, 676	67, 088	[illegible]	787	71, 717	11, 957	1, 861	13, 818	1, 141
[illegible]	21, 595	13, 579	1, 817		15, 396	5, 899	81	5, 980	219

Measurement and Summation of Areas.

The field mapping resulted in pictured areas, to scale, of 18 classifications of land and water. It remained to convert these pictures to classified acreage, under various summations. The acreage of a single tract of alfalfa, say, was of no interest; the total acreage of alfalfa on a field sheet was desired. The method of measuring areas, in connection with field maps resulting from aerial photographs (p. 409), was fast and accurate and as far as known, unprecedented in such use.

Photostats from the aerial views were made to something approximating exact scale and these used in the field. A field was identified as to location and the crop-class number or color is penciled on the print.

Two methods of acreage determination were used in the Rio Grande work. Both employed sheet celluloid as a medium. For the more complex areas, the boundaries and class numbers of the tract were traced on drafting linen. This linen was then secured by small office staples, between two sheets of celluloid, each 0.0075 inch thick. The whole assembly was then weighed on a precision chain balance. The various areas were then cut out, opposite pieces of celluloid were dropped in numbered compartments, and the intervening piece of linen was saved. The celluloid fragments in each compartment were carefully weighed at one time and the weights were tabulated. From some unmapped part of the celluloid assembly sheet, areas of exactly 1,000 acres or some other known size, were cut around a template. This test block and the remnants of celluloid and linen remaining after the cutting of the areas were also weighed. Obviously the sum of the weights of the classed fragments, test block, and remnants must equal the first weight of the whole assembly. If the variation was greater than one part in 1,000 the work was repeated until the error was found. Thus, the acreage of perhaps 50 tracts of alfalfa was determined at one operation, whereas the use of the planimeter would have permitted only one tract at a time to be measured. The field sheet itself remained as the permanent record.

Where the fields largely conformed to the sectionized land, in nicely squared tracts, a simpler method was used. Celluloid 0.015 inch thick was laid over the field sheet and the boundaries and numbers of classified lands were traced with a sharp point held at an acute angle with the sheet. This cut a mark without removing shavings. The celluloid was weighed and the weight was recorded. The various tracts and a test block were then broken out by bending on the scratched lines. The rest of the process was unchanged. The weight of the test block was then adjusted two ways: (a) The field photostat was compared for true scale with surveyed distances, such as highway or railroad tangent lengths. Thus a coefficient of area was determined. (b) The test block weight was then adjusted to include the 3-percent and the 1-percent deductions as explained on page 405. The tabulated computations of some 60 columns were then completed by means of a 20-inch slide rule. From these detail summations tables A, B, and C, shown on the following pages, were finally developed.

TABLE A.—*Lands under irrigation and other water-using*

	[illegible]	Agricultural and other lands artificially given water				[illegible]				
	[illegible]	[illegible]	[illegible]	Cities, towns, and [illegible]	Total [illegible] "out" [illegible]	[illegible] vege- [illegible]	[illegible] and river-bed surfaces	[illegible] nonirrigated	[illegible] formerly irrigated [1]	Bare land, roads, rights-of-way, etc.
[illegible]	[illegible]	[illegible]	18,979	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	70,410
[illegible]	[illegible]	[illegible]	[illegible]	1,034	287,831	404,014	4,010	408,024	84,445	37,570
[illegible]	[illegible]	[illegible]	8,677	[illegible]	182,168	141,795	[illegible]	142,750	49,486	8,987
[illegible]	[illegible]	56,792	2,947	11	59,750	4,227	313	4,540	1,354	757
[illegible]	[illegible]	[illegible]	[illegible]	11	51,534	[illegible]	270	4,339	1,354	651
Via Farmers' Union Canal (San Luis Valley Irrigation District)	[illegible]	[illegible]	[illegible]		4,857	107	26	133		[illegible]
Via Prairie ditch	[illegible]	[illegible]	[illegible]		[illegible]	11	[illegible]	[illegible]		[illegible]
[illegible]	[illegible]	[illegible]	4,053	271	54,272	[illegible]	[illegible]	[illegible]	31,671	5,986
[illegible]	[illegible]	[illegible]	[illegible]	132	17,667	14,208	[illegible]	[illegible]	6,394	1,532
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9,785	14,097	[illegible]	14,147	6,160	2,078
Via San Luis Canal (Mosca Irrigation District)	[illegible]	[illegible]	1,130	14	7,902	25,500	41	25,541	16,740	[illegible]
Via miscellaneous ditches, including above, mixed	[illegible]	7,110	[illegible]		7,522	39,656	[illegible]	39,890	3,086	[illegible]
[illegible]	95,791	11,396	[illegible]		[illegible]	82,648	763	[illegible]	[illegible]	987
[illegible]	[illegible]	171,182	1,875	[illegible]	173,809	223,678	2,504	226,182	48,420	30,847
[illegible]	53,715	43,212	[illegible]		[illegible]	[illegible]	250	8,493	[illegible]	1,491
[illegible]	17,887	[illegible]			[illegible]	[illegible]	[illegible]	8,052	[illegible]	[illegible]
[illegible]	55,726	25,492	1,158	[illegible]	[illegible]	[illegible]	144	[illegible]	11,015	821
[illegible]										
[illegible]	4,520	2,057	[illegible]		2,102	2,385	[illegible]	2,396	[illegible]	22
[illegible]	1,751	[illegible]			[illegible]	414		414	285	[illegible]
[illegible]	117,328	41,662	[illegible]	228	41,890	56,804	758	57,562	17,656	17,876
[illegible]	35,022	[illegible]	[illegible]	38	16,049	14,737	[illegible]	14,820	[illegible]	[illegible]
[illegible]	1,297	1,123		[illegible]	1,161	[illegible]	6	101	[illegible]	32
San Luis Creek and eastern tributaries, mixed	33,725	14,746	112		[illegible]	14,639	77	14,716	3,786	4,121
Miscellaneous, east side	[illegible]	[illegible]	[illegible]	221	30,736	[illegible]	[illegible]	90,966	6,068	[illegible]
Seepage water from west side sources mixed	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	15,489	4,292	[illegible]
[illegible]										
[illegible]	[illegible]	[illegible]	[illegible]	11	[illegible]	[illegible]	[illegible]	20,884	6,091	2,470
[illegible] Union Canal	91,280	[illegible]	[illegible]	[illegible]	19,439	42,161	[illegible]	42,436	17,409	[illegible]
[illegible]	29,471	12,043	976	125	[illegible]	[illegible]	67	[illegible]	6,160	2,112
[illegible]	34,328	[illegible]	1,130	14	[illegible]	[illegible]	[illegible]	[illegible]	16,740	[illegible]
[illegible]	[illegible]	[illegible]	8,875	1,034	[illegible]	[illegible]	[illegible]	[illegible]	84,445	37,570
Rio Grande (part of)	[illegible]	56,792	2,947	11	[illegible]	[illegible]	[illegible]	[illegible]	1,354	757
[illegible]	237,560	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	177,302	31,671	[illegible]
[illegible]	430,838	171,182	1,875	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	48,420	30,847
[illegible]										
[illegible]	482,531	270,350	7,228	4,103	[illegible]	[illegible]	[illegible]	[illegible]	57,318	18,110
[illegible]										
Wright's ranch in Mineral County to line between ranges [illegible]	[illegible]	11,901	[illegible]	72	11,967	2,168	1,164	3,332	718	[illegible]
[illegible]	17,240	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	321	[illegible]	13,679
South Fork, Schraders, and Pinos Creeks	10,478	[illegible]	[illegible]		[illegible]	[illegible]	79	1,340	[illegible]	[illegible]
Rio Grande and tributaries, south and west of main stem:										
[illegible]										
[illegible]	[illegible]	21,382	[illegible]	19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Empire Canal	64,341	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39,961	3,408	2,649
Small canals and ditches	74,211	39,675	[illegible]	1,934	[illegible]	[illegible]	912	30,967	[illegible]	1,367
[illegible]										
Alamosa Creek alone (including Terrace Irrigation District)	36,187	8,768	1,779	12	10,559	[illegible]	398	23,607	21,530	2,021
[illegible]	570	[illegible]		[illegible]	313	248	[illegible]	[illegible]		7
[illegible] Canal, combined and mixed (including Terrace Irrigation District)	63,663	40,005	2,074	371	[illegible]	19,882	220	20,102	[illegible]	[illegible]
[illegible]	14,171	[illegible]	[illegible]	102	7,919	3,804	[illegible]	4,019	2,087	[illegible]
[illegible]	4,769	3,329	[illegible]	1	3,479	[illegible]	[illegible]	1,012	129	[illegible]
[illegible]	101,531	71,365	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4,856
(Terrace Irrigation District, within exterior boundaries)	17,930	[illegible]	1,570	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	116
Rio Grande, north of main stem										
[illegible]	[illegible]	11,078	[illegible]		[illegible]	2,153	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]		1,505	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Small canals and ditches	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Southeast area, by streams	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]			[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4,268	4,430
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,307	1,801
[illegible]	[illegible]	[illegible]	337		[illegible]	[illegible]	444	17,601	2,125	2,336
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6,170	[illegible]	[illegible]

[1] Included in classifications 9a and 9b. Not duplicated in totals.

areas in Rio Grande Basin in Colorado, in acres, 1936

[illegible]																	
[illegible]										[illegible]			[illegible]				
Cotton	Alfalfa [illegible] hay	Native [illegible]	Irrigated [illegible]	Early annuals	Late [illegible]	[illegible] laneous crops	Double cropped areas	Cities, towns, and villages	Land temporarily out of cropping	[illegible]	Brush	[illegible] bosque	Pooled water	River and canal surfaces and exposed beds	[illegible] formerly irri-[illegible]	[illegible] land, [illegible] of-way, etc.	[illegible]
[illegible]	[illegible]	(3)	[illegible]	[illegible]	(6)	(7)	(10)	(11)	(8)	(9a)	[illegible]	[illegible]	(9d)	(9e)	(12)	(13)	
	11,[illegible]	143,766	139,119	131,492	51,576	16,563		6,029	18,979	206,259	505,096	25,844	5,313	8,419	158,691	70,440	
	50,591	69,841	79,760	48,441	28,775	[illegible]		1,034	8,875	129,460	272,919	1,635	2,521	1,489	[illegible]	37,570	
	[illegible]	15,680	37,286	47,342	28,471	123		547	8,677	32,813	108,115	867		955	[illegible]	8,987	
	14,741	196	[illegible]	23,612	15,774	[illegible]		11	2,947	1,272	2,483	472		313	1,354	737	
	12,201	196	2,159	20,428	13,576	[illegible]		11	2,865	1,143	2,454	472		270	1,354	651	
	1,696		212	1,443	1,479				27	78	29			[illegible]		52	
	[illegible]			1,741	719				[illegible]	51				17		[illegible]	
	[illegible]	4,659	16,912	8,634	3,347	112		271	4,053	[illegible]	118,913	164	919	274	34,671	5,986	
	[illegible]	[illegible]	4,261	3,771	1,749			132	[illegible]	[illegible]	9,580	40	12	93	6,394	1,532	
	3,993	135	1,009	2,474	1,128			125	921	4,373	[illegible]			[illegible]	6,160	2,078	
	3,890	[illegible]	1,175	955	220	11		14	1,130	3,540	21,960			41	16,740	[illegible]	
	1,878	342	3,206	1,434	250				412	5,643	33,997	16	204	30	[illegible]	504	
	[illegible]	3,514	7,261			98				38,888	43,652	108	763	60	2,291	987	
	[illegible]	64,986	60,477	[illegible]	9,654	304		752	1,875	71,156	151,523	999	1,602	902	48,420	30,847	
	5,269	6,180	16,731	[illegible]	5,787				[illegible]	3,840	4,139	[illegible]		230	3,700	1,491	
	189	[illegible]	[illegible]	4	27					2,677	5,321			54	1,037	939	
	8,082	5,214	2,802	5,847	3,536	11		265	1,158	6,880	20,911	[illegible]		144	11,015	821	
	[illegible]	473	[illegible]	233	78	32			45	33	2,352			11	561	22	
	242	344	297	110	36	23					296	118			285	285	
	2,635	22,560	16,047	316	104			228		22,475	33,980	349	547	211	17,656	17,876	
	2,218	9,486	3,847	[illegible]	72			38	142	758	13,899	80		83	3,806	4,153	
	99	987		11	26			38		18		80		6	[illegible]	32	
	2,119	[illegible]	[illegible]	[illegible]	46				142	740	13,899			77	3,786	4,121	
	625	17,407	12,119	115		238		221	11	32,793	57,058	113	840	162	6,068	5,086	
	51	377	1,917	79	14					1,700	13,567		215	7	4,292	174	
	[illegible]	9,321	24,621	29,677	19,390	98		11	3,384	7,660	11,914	756		554	6,091	2,430	See same captions in [illegible] area tabulations.
	[illegible]	5,378	7,275	[illegible]	6,764	11		397	2,775	11,546	30,520	95	12	263	17,409	2,405	
	4,837	[illegible]	1,009	4,215	1,847			125	976	[illegible]	[illegible]			67	6,160	2,112	
	[illegible]	[illegible]	1,175	955	220	14		14	1,130	3,540	21,960			41	[illegible]	885	
	50,591	69,841	79,760	48,441	28,775	514		1,034	8,875	129,460	272,919	1,635	2,521	1,489	84,445	37,570	
	14,741	[illegible]	2,371	[illegible]	15,774	98		11	2,947	1,272	[illegible]	472		313	1,354	737	
	[illegible]	4,659	[illegible]	[illegible]	3,347	112		271	4,053	57,032	[illegible]	[illegible]	919	274	34,671	5,986	
	[illegible]	64,986	60,477	16,195	9,654	304		752	1,875	71,156	151,523	999	1,602	902	48,420	30,847	
	57,512	69,508	47,723	63,572	22,492	9,543		4,103	7,228	32,538	123,740	19,913	884	5,665	57,318	18,110	
	[illegible]	4,619	[illegible]	1,722	[illegible]	1,733		52	14	225	518	1,425	424	740	718	913	
	1,027	[illegible]	[illegible]	914	[illegible]	60			[illegible]	111	158			[illegible]	1,220	13,679	
	1,212	2,558	1,256	1,240	1,342	929		9	53	193	320	748		79	[illegible]	539	
	7,587	4,449	1,636	6,975	3,735			19	371	1,196	6,716	16		130	906	682	
	9,901	420	1,451	6,040	2,844	138		12	925	6,740	33,086		20	115	3,308	2,649	
	3,404	14,724	11,708	6,014	[illegible]	419		1,934	268	3,096	20,027	6,932	81	831	2,493	1,367	
	3,073	243	432	2,953	1,640	427		12	1,779	1,161	20,988	1,060	36	362	21,530	2,021	
	51		54	117	21	22		68		6		242		2		7	
	7,901	14,734	4,760	8,420	1,766	2,424		371	2,074	3,229	15,301	1,352		220	4,593	1,111	
	1,878	1,122	2,100	1,985	206	404		102	122	1,493	313	1,998		215	2,087	2,236	For New Mexico portion see table B.
	[illegible]	421	344	1,738	161	159		1	119	57	15	921		19	129	278	
	16,192	19,569	9,802	19,191	4,122	2,489		1,523	836	4,538	12,237	4,042	188	1,946	11,159	4,856	
	2,500		40	2,200	1,555	160		10	1,570	194	9,527			58	9,527	116	
	972	552	3,279	3,890	2,265	120			277	180	1,691	282		60	1,729	502	See [illegible] captions in closed basin.
	792	38	445	158	38	5			29	2,920	1,650			8	4,545	63	
	3,338	6,059	7,611	3,129	689	274			331	7,504	10,878	805	[illegible]	938	3,557	886	
	9,324	4,417	11,936	19,479	309	6,506		892	2,876	[illegible]	108,437	4,296	1,908	1,295	16,931	14,760	
	24	151	686							8,336	9,452				236	416	
	3,263	2,830	6,433	4,213	88	1,828		236	235	19,245	38,894	[illegible]	942	315	4,268	4,430	
	2,711	471	2,974	3,566	85	1,657		123	169	13,843	23,032	1,353	572	57	1,307	1,801	
		921	3,372	246					37	4,082	12,727	348	201	243	2,125	2,336	
	[illegible]	1,458	87	401		171		113	29	1,320	3,135	1,831	169	15	836	293	

TABLE A.—*Lands under irrigation and other water-using* [illegible]

[illegible]	Total area [illegible]	[illegible]	Temporarily out of [illegible]	Cities, towns, and villages	Total irrigated "out" and towns	Native vegetation	[illegible] and river-[illegible] surfaces	Total [illegible]	[illegible]	Bare land, roads, [illegible] way, etc
	Mapped areas									
		Agricultural and other lands artificially given water				[illegible]				
[illegible]	[illegible]	[illegible]	2,115	554	[illegible]	61,300	1,162	[illegible]	9,952	7,742
[illegible]	[illegible]	1,264	143	[illegible]	1,428	241	327	[illegible]	242	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,911
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,921
[illegible]										
[illegible]	[illegible]	6,673			6,673	115	1,122	1,237	[illegible]	[illegible]
[illegible]	186,402	136,892	4,755	[illegible]	142,806	36,554	857	37,411	13,181	[illegible]
[illegible]	395,976	108,734	4,812	1,161	114,707	269,124	3,097	272,221	44,190	[illegible]
[illegible]	213,806	125,652	1,661	[illegible]	132,378	68,522	[illegible]	71,501	[illegible]	[illegible]
[illegible]	211,631	51,110	[illegible]	[illegible]	54,878	[illegible]	[illegible]	142,409	[illegible]	[illegible]
[illegible]	430,838	171,182	[illegible]	[illegible]	173,809	[illegible]	[illegible]	226,182	[illegible]	[illegible]

[illegible]

TABLE B.—*Lands under irrigation and other water-using* [illegible] *Rio Grande Basin*.

Unit	Total area [illegible]	Irrigated in 1936	[illegible] rarily out of cropping	Cities, [illegible] and [illegible]	Total [illegible] "out" and [illegible]	Native vegeta-[illegible]	[illegible] and river bed sur-[illegible]	Total nonirrigated	Bare land, roads, rights-of-[illegible]
	Mapped areas								
		Agricultural and other lands artificially [illegible]				Other water using areas, nonirrigated			
[illegible]	[illegible]	152,782	13,187	10,251	176,220	[illegible]	[illegible]	180,275	10,414
Main stem of Rio Grande	217,954	65,969	[illegible]	6,398	76,051	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	83,115	46,685	[illegible]	1,540	54,775	[illegible]	[illegible]	[illegible]	[illegible]
East side tributaries	65,840	[illegible]	[illegible]	2,313	45,394	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	65,969	3,684	[illegible]	[illegible]	106,853	[illegible]	[illegible]	[illegible]
[illegible]	378	191	3	8	[illegible]	11	148	169	
[illegible]	9,349	1,894	[illegible]	[illegible]	5,140	2,243	[illegible]	[illegible]	240
[illegible]	3,151	[illegible]	50	[illegible]	[illegible]	1,377	[illegible]	[illegible]	[illegible]
[illegible]	187,682	[illegible]	2,980	6,165	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Cochiti Division (all in Sandoval County)	19,439	[illegible]	[illegible]	101	5,778	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	58,127	22,819	[illegible]	4,241	[illegible]	[illegible]	[illegible]	29,233	[illegible]
[illegible]	15,214	4,611	[illegible]	[illegible]	[illegible]	7,985	[illegible]	9,702	[illegible]
[illegible]	42,913	18,208	[illegible]	3,993	[illegible]	[illegible]	1,021	19,531	143
Belen Division	[illegible]	23,895	1,165	530	[illegible]	[illegible]	6,779	47,573	[illegible]
[illegible]	[illegible]	16			[illegible]	[illegible]		543	[illegible]
[illegible]	[illegible]	20,335	865	[illegible]	21,641	27,151	2,731	30,182	[illegible]
In Socorro County	[illegible]	3,514	[illegible]	[illegible]	3,903	12,800	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	236	[illegible]	[illegible]	[illegible]	1,782	[illegible]	[illegible]
Socorro Division (all Socorro County)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	9,349	[illegible]	[illegible]	205	5,140	[illegible]	1,426	[illegible]	240
Santa Fe	3,151	[illegible]	[illegible]	[illegible]	856	1,377	[illegible]	2,149	116
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10,812	19,217	[illegible]	22,462	1,379
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20,074	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

areas in Rio Grande Basin in Colorado, in acres, 1936—Continued

Identification of areas by classification numbers																	Remarks
Land irrigated in 1936								Cities, towns, and villages	Land temporarily out of cropping	Native vegetation			Water areas		Areas formerly irrigated [1]	Bare land, roads, rights-of-way, etc.	
Cotton	Alfalfa and clover hay	Native hay	Irrigated pasture	Early annuals	Late annuals	Miscellaneous crops	Double cropped areas			Grass	Brush	Trees, bosque	Pooled water	River and canal surfaces and exposed beds			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(10)	(11)	(8)	(9a)	(9b)	(9c)	(9d)	(9e)	(12)	(13)	
	[illegible]	[illegible]	4,722	14,175	221	[illegible]		554	2,115	16,422	44,114	764	[illegible]	640	9,952	7,742	For New Mexico portion see table B.
	[illegible]		17	[illegible]		[illegible]		21	143	61	180			327	242	261	
	445		18	645		1,006		81	383	197	15,797		111	13	2,233	1,911	Do.
	[illegible]	[illegible]	[illegible]	1,181	180	1,083		81	158	143	180	187		[illegible]	242	289	Do.
	[illegible]		18	732	[illegible]	1,056		81	383	2,833	15,797		111	13	2,869	1,921	Do.
		3,884	2,638	151						99		16	424	698	23	89	
	[illegible]	[illegible]	18,077	42,141	[illegible]	3,471		1,159	4,755	6,124	22,206	8,224	81	776	13,181	6,185	
	[illegible]	25,438	31,356	17,475	6,757	388		1,161	4,812	82,269	184,161	2,694	1,054	2,043	44,190	9,048	
	62,742	27,123	15,621	36,051	8,221	5,894		2,065	4,661	10,686	48,221	9,645	214	2,735	36,185	9,927	
	[illegible]	4,266	11,250	19,479	[illegible]	6,506		892	2,876	35,925	98,985	4,296	1,908	1,295	16,695	14,344	
	[illegible]	[illegible]	60,477	16,195	9,654	304		752	1,875	71,156	151,523	999	1,602	902	48,420	30,847	

from Colorado-New Mexico State line to San Marcial, N. Mex., in acres, 1936

Identification of areas by classification numbers																	Remarks
Land irrigated in 1936								Cities, towns, and villages	Land temporarily out of cropping	Native vegetation			Water areas		Areas formerly irrigated	Bare land, roads, rights-of-way, etc.	
Cotton	Alfalfa and clover hay	Native hay	Irrigated pasture	Early annuals	Late annuals	Miscellaneous crops	Double cropped areas			Grass	Brush	Trees, bosque	Pooled water	River and canal surfaces and exposed beds			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(10)	(11)	(8)	(9a)	(9b)	(9c)	(9d)	(9e)	(12)	(13)	
56	33,775	24,197	9,422	31,055	35,575	18,702		10,251	13,187	60,796	34,942	45,172	1,300	38,065		10,414	
56	18,621	7,278	3,130	8,210	18,862	9,812		6,398	3,684	45,202	21,517	40,114	584	26,524		7,962	
	8,999	12,661	2,370	8,381	10,696	3,578		1,540	6,550	6,792	8,257	2,702	695	8,915		979	
	6,155	4,258	3,922	14,464	6,017	5,312		2,313	2,953	8,802	5,168	2,356	21	2,626		1,473	
56	18,621	7,278	3,130	8,210	18,862	9,812		6,398	3,684	45,202	21,517	40,114	584	26,524		7,962	
	18	25		4	54	90		8	3	31				138		7	No irrigation.
	775	715	430	540	1,162	1,272		205	341	302	1,269	672		1,426		240	
	116	306	77	71	186	50		20	30	12	307	1,058		772		146	No irrigation.
56	17,434	6,232	2,333	7,402	17,460	8,242		6,165	2,980	43,968	19,639	26,794	154	21,741		7,082	
	698	941	533	1,035	1,683	318		401	169	2,628	4,417	4,187		1,528		901	
	7,221	2,240	815	1,854	6,683	4,006		4,241	913	10,487	4,968	8,040		5,738		921	
	1,290	526	326	488	1,133	848		248	175	2,396	1,657	3,932		1,717		478	
	5,931	1,714	489	1,366	5,550	3,158		3,993	738	8,091	3.311	4,108		4,021		443	Includes Albuquerque.
	7,883	2,529	735	2,951	6,331	3,466		530	1,165	26,540	7,149	7,105	140	6,639		3,881	
	4	40			2					261	200	82				5	
	7,224	2,296	315	2,269	5,340	2,891		441	865	18,228	6,231	2,992	52	2,679		3,565	
	655	193	420	682	989	[illegible]		89	300	8,051	718	4,031	88	3,960		311	
	506	164	283	599	849	494		41	236	4,937	201	1,919	62	1,720		201	
	149	29	137	83	140	81		48	64	3,114	517	2,112	26	2,240		110	
[illegible]	1,632	522	250	1,562	2,763	452		993	733	4,313	3,105	7,462	14	7,836		1,379	Including Socorro.
										784		9,380		1,970		419	
	278		290	193		158			330	105	302	2,210	430	477		38	
	18	25		4	54	90		8	3	31				138		7	
	775	715	430	540	1,162	1,272		205	341	302	1,269	672		1,426		240	
	116	306	77	71	186	50		20	30	12	307	1,058		772		146	
	1,988	1,467	859	1,523	2,816	1,166		649	344	5,024	6,074	8,119		3,245		1,379	
	5,935	1,754	489	1,366	5,552	3,158		3,993	738	8,352	3,511	4,190		4,021		448	
	7,224	2,296	315	2,269	5,340	2,891		441	865	18,228	6,231	2,992	[illegible]	2,679		3,565	
56	2,565	715	960	2,437	3,752	1,185		1,082	1,363	13,253	4,125	23,083	532	14,243		2,177	
	891	1,021	507	611	1,348	1,322		225	371	314	1,576	1,730		2,198		386	
	16,544	6,702	2,453	6,368	15,905	9,031		5,349	2,554	36,855	17,593	18,950	114	13,863		5,979	

TABLE [illegible].—[illegible]

[illegible]	Total area mapped	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Total nonirrigated	Bare land, [illegible] ways, etc.
[illegible]	[illegible]	46,685	[illegible]	[illegible]	54,775	17,751	9,610	27,361	[illegible]
[illegible]	[illegible]	511	[illegible]	5	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	....	8	[illegible]	33	22		
[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	5	421	
[illegible]	[illegible]	[illegible]	[illegible]	2	[illegible]	[illegible]	11	1,486	278
[illegible]	[illegible]	28,613	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17,142	[illegible]
[illegible]	[illegible]	7,921	122	[illegible]	[illegible]	[illegible]	[illegible]	5,910	[illegible]
[illegible]	13,448	7,179	122	316	[illegible]	[illegible]	[illegible]	5,714	117
[illegible]	1,006	742			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	812	159	[illegible]	4,767	1,437	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	321	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20
[illegible]	[illegible]	[illegible]	[illegible]	131	[illegible]	[illegible]	[illegible]	5,125	157
[illegible]	[illegible]	[illegible]			356	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	6,977	4,392	211	117	4,720	2,002	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	14	4,151	[illegible]	[illegible]	[illegible]	58
Rio Chama and tributaries below Abiquiu	[illegible]	[illegible]	[illegible]	81	11,413	[illegible]	[illegible]	[illegible]	126
[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	81	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]		17	[illegible]	[illegible]	[illegible]	[illegible]	5
[illegible]	[illegible]	[illegible]	[illegible]	8	6,031	[illegible]	342	1,179	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	56	[illegible]	[illegible]	[illegible]	1,181	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]		[illegible]				
[illegible]	6,644	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Rio Puerco and tributaries (in Sandoval and Valencia Counties)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	464
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	64
Tributaries	20,616	10,[illegible]	[illegible]	[illegible]	15,193	3,442	1,581	5,023	400
[illegible]	5,922	[illegible]	[illegible]	[illegible]	4,366	1,169	332	1,501	[illegible]
San Jose River and tributaries below Grant	14,694	7,145	[illegible]	783	[illegible]	[illegible]	1,249	[illegible]	342
[illegible]	10,145	5,072	[illegible]	505	[illegible]	[illegible]	1,133	2,667	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Totals, west side tributaries, by counties:									
[illegible]	318	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	216	
[illegible]	49,011	[illegible]	1,207	[illegible]	[illegible]	[illegible]	[illegible]	17,618	468
Sandoval	13,170	[illegible]	1,306	[illegible]	[illegible]	[illegible]	1,840	[illegible]	111
Bernalillo									
[illegible]	20,616	10,372	4,021	[illegible]	15,193	3,442	[illegible]	[illegible]	400
[illegible]	318	63	[illegible]	[illegible]	102		[illegible]	[illegible]	
[illegible]	65,840	40,128	[illegible]	[illegible]	45,394	16,3[illegible]	[illegible]	[illegible]	1,473
[illegible] Mexico via Colorado (Costillo and Culebra Creeks mixed):[3]	2,834	188			188	2,636		[illegible]	10
[illegible]	3,364	2,696	15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	2,332	[illegible]	81	2,796	18,630	457	19,087	1,921
[illegible]	5,621	[illegible]	158	[illegible]	4,199	510	[illegible]	1,133	[illegible]
[illegible]	3,875	2,402	[illegible]	24	2,578	1,236	25	1,261	[illegible]
[illegible]	[illegible]	2,846	150	[illegible]	3,176	[illegible]	15	[illegible]	124
[illegible]	[illegible]	[illegible]	58	[illegible]	649	31	15	44	[illegible]
[illegible]	[illegible]	[illegible]			[illegible]	116	[illegible]	119	2
[illegible]	1,028	[illegible]	[illegible]	[illegible]	840	[illegible]	[illegible]	178	10
[illegible]	[illegible]	2,912	[illegible]	[illegible]	[illegible]	1,927	15	1,942	[illegible]
[illegible]	[illegible]	11,191	817	[illegible]	12,330	2,253	87	[illegible]	145
Embudo Creek and tributaries[4]	[illegible]	5,828	182	176	6,186	1,168	303	1,771	[illegible]
[illegible]	[illegible]	5,362	149	121	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	5,361	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Rio Arriba	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,461	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	1,468	[illegible]	[illegible]	[illegible]	[illegible]	888

[illegible]

from Colorado-New Mexico State line to San Marcial, N. Mex., in acres, [illegible]—Continued

Cotton	Alfalfa and [illegible]	Native [illegible]	Irrigated pasture	Early [illegible]	Late annuals	Miscellaneous [illegible]	Double cropped areas	Cities, towns, and villages	Land temporarily out of cropping	[illegible]	Brush	Trees, bosque	Pooled water	River and canal surfaces and [illegible] beds	Areas formerly irrigated	[illegible] land, roads, rights-of-way, etc.	[illegible]
(1)	(2)	(3)	(4)	[illegible]	(6)	[illegible]	[illegible]	(11)	(8)	[illegible]	(9b)	[illegible]	(9d)	[illegible]	(12)	(13)	
	[illegible]	12,661	2,370	8,381	10,696	3,578		1,540	[illegible]	6,792	8,257	2,702	695	8,915		979	
	[illegible]	[illegible]		134	213	[illegible]		8	51	112	[illegible]	274		[illegible]			[illegible] Table A
	[illegible]	33			15	2		8		[illegible]				22			[illegible]
	48	[illegible]		134	198	53			[illegible]	79	65	274		3			[illegible]
	[illegible]	[illegible]	[illegible]	1,872	374	214		9	200	167	80	1,195		44		278	
	[illegible]	[illegible]	2,355	5,312	4,011	2,243		556	1,156	3,165	5,881	2,145	15	5,933		468	
	1,897	1,853	[illegible]	2,404	427	404		316	122	1,601	1,908	670		[illegible]		185	
	1,872	1,334	923	2,294	391	362		316	122	1,444	1,872	670		1,728		117	
	[illegible]	519	13	110	[illegible]	42				157	36			3		68	
	1,801	2,047	1,097	1,676	1,910	1,051		[illegible]	812	1,103	2,880	784	15	1,422		157	
	[illegible]	[illegible]	[illegible]	101	[illegible]	127		28	321	74	34	478		493		20	
	1,559	2,007	873	1,572	[illegible]	924		131	491	1,029	2,846	306	[illegible]	929		137	
	[illegible]	[illegible]		103	64	[illegible]				147	154	287		2		[illegible]	
	829	1,041	[illegible]	1,136	721	619		117	211	670	1,332			186		69	
	670	857	827	333	885	285		11	280	212	1,360	19	15	741		[illegible]	
	[illegible]	6,127	322	1,232	[illegible]	788		81	222	461	1,096	691		2,780		126	
	414	415	311	133	[illegible]	323			150	142	310	[illegible]		1,111		57	
	553	5,712	11	1,099	[illegible]	465		81	72	319	786	140		1,669		69	
	127	87		[illegible]	114	41		17		6	120			428		[illegible]	
	131	5,083	6	402	[illegible]	94		8	27	273	345	19		542		[illegible]	
	[illegible]	529	5	605	[illegible]	323		56	20	40	321	121		699		28	
		13		23	10	7			25								
	492	135	8	861	732	268		2	379	656	1,095	233	59	1,677		47	
	3,783	2,414		2,074	5,700	1,001		948	4,951	2,859	1,213	50	621	1,064		[illegible]	
	1,205	75		1,111	[illegible]	339		151	927	386	283	11	51	[illegible]		64	All irrigated land is in Sandoval County.
	2,578	2,339		963	3,830	662		797	4,024	2,473	930	39	570	1,011		400	
	1,071	261		716	1,032	147		14	1,125	744	425		58	274		55	Bluewater Creek becomes San Jose River near Grant
	1,507	2,078		247	2,798	515		783	2,899	1,729	505	39	512	737		345	
	1,025	1,945		133	1,688	281		505	1,597	1,214	320		486	647		304	All irrigated land is in Valencia County.
	482	133		114	1,110	234		278	1,302	515	185	39	26	90		41	
	5		7		40	11		26	13					216			All irrigated land is in Socorro County.
	4,719	10,112	2,355	5,446	4,224	2,298		564	1,207	3,277	5,949	2,419	15	5,958		468	
	1,697	210	8	1,972	2,602	607		153	1,306	1,042	1,378	244	110	1,730		111	
																	No irrigation on west side tributaries.
	2,578	2,339		963	3,830	662		797	4,024	2,473	930	39	570	1,011		400	
	5		7		40	11		26	13					216			
	6,155	4,258	3,922	14,464	6,017	5,312		2,313	2,953	8,802	5,168	2,356	21	2,626		1,473	
	46			87	5	[illegible]				2,636						10	
	331	618	52	1,038	180	477		60	15	82		187		296		28	
	491		48	732	5	1,056		81	383	2,833	15,797		444	13		1,921	
	496	618	99	1,484	180	1,083		81	158	143	180	187		623		289	
	484	85	25	1,272	174	364		24	152	216	779	241	15	12		36	
	375	370	244	1,642	160	57		180	150	390	39	417		15		124	
	71	96	90	223	81	15		5	38	10	21			13		6	
	34	49	52	39	75	14				100	16			3		2	Irrigation from seepage.
	23	95	217	235	126	68		11	65	145	29			4		10	
	425	33	215	1,366	309	564		18	579	455	823	649		15		30	
	2,107	1,020	2,088	3,875	1,424	677		322	817	1,214	832	207		87		145	No irrigation from Taos Creek.
	282	1,144	288	2,490	997	627		176	182	873	746	49		303		78	
	279	1,095	270	2,477	736	505		121	149	864	[illegible]	47		218		72	
	124	400	126	862	356	215		82	[illegible]	336	[illegible]	6		141		26	
	155	695	144	1,615	380	290		39	114	528	483	41		77		46	
	3	49	18	13	261	122		55	33	9	13	2		85		6	
	29	146		378	64	[illegible]		10		119	70			104		8	
	81	134	10	757	229	268		22	97	485	414	34		8		25	
	707	280	314	331	888	1,108		64	202	333	487	170		372		346	
	131	544	128	44	181	337		17	27	12	87	12		4		83	
	[illegible]	226	186	387	707	771		47	[illegible]	321	400	158		[illegible]		263	
	958	105	239	[illegible]	[illegible]	576		131	254	583	436	315	4	963		329	
	201	85	88	131	[illegible]	389		1,253	360	870	568	87	4	431		292	
								1,082									
	3				7	29		37	42	288	108					4	
	4,173	3,459	3,253	12,254	3,270	[illegible]		[illegible]	1,965	6,112	3,072	1,748	13	663		163	
	244	383	156	1,192	735	[illegible]		104	157	628	[illegible]	48		201		[illegible]	
	1,738	416	513	1,018	2,012	1,765		1,468	831	2,062	1,512	560	8	[illegible]		[illegible]	

TABLE C.—*Lands under irrigation and other water-using areas in Rio Grande*

Unit	Total area mapped	Irrigated [illegible]	Temporarily out of cropping	Cities, towns, and villages	Total irrigated "out" and towns	[illegible] vegetation	Water [illegible]	Total nonirrigated	Bare land, roads, rights-of-way, etc.
[illegible]	[illegible]	[illegible]	14,153	2,633	[illegible]	[illegible]	[illegible]	[illegible]	5,671
[illegible]	[illegible]	[illegible]	[illegible]	1,846	[illegible]	[illegible]	[illegible]	66,432	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	787	87,113	17,856	[illegible]	19,798	1,360
[illegible]									
[illegible]	[illegible]	[illegible]	[illegible]	1,708	97,865	[illegible]	10,825	[illegible]	[illegible]
[illegible]	[illegible]					19,281	3,384	[illegible]	692
[illegible]	[illegible]					[illegible]		2,790	
[illegible]	[illegible]	[illegible]	[illegible]	304	[illegible]	7,435	1,190	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	1,404	[illegible]	[illegible]	[illegible]	24,855	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]		3,111	[illegible]	[illegible]	2,524	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17,445	7,310	2,665	9,975	[illegible]
[illegible]	[illegible]	72,258	5,283	1,294	78,785	11,294	3,586	[illegible]	2,915
[illegible]	54,216	40,571	3,402	295	44,268	[illegible]	1,653	7,854	2,094
[illegible]	[illegible]	31,687	1,831	[illegible]	34,517	5,093	1,933	7,026	[illegible]
[illegible]	[illegible]	1,608	631	138	2,377	4,096	3,401	[illegible]	[illegible]
[illegible]	[illegible]	693	[illegible]	15	957	1,407	684	[illegible]	24
[illegible]	[illegible]	[illegible]	144	[illegible]	414	1,182	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]		117	1,124	785	[illegible]	15
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	136	[illegible]	321	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	1,523	[illegible]	13,198	4,081	[illegible]	3,124
[illegible]	[illegible]	[illegible]	[illegible]	787	87,113	17,856	1,942	[illegible]	1,360
[illegible]	13,838	10,665	336	[illegible]	11,230	[illegible]	495	2,399	[illegible]
[illegible]	[illegible]	56,423	3,506	558	60,487	10,053	[illegible]	11,419	932
[illegible]	[illegible]	[illegible]	3,842	787	71,717	11,957	[illegible]	13,818	1,141
[illegible]	21,595	13,579	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	219
[illegible]	211,170	154,552	[illegible]	[illegible]	[illegible]	30,561	[illegible]	[illegible]	[illegible]
[illegible]	[2] 16,674								
[illegible]									
[illegible]	23,357					19,281	3,384	22,665	[illegible]
Sierra	18,808	[illegible]	946	[illegible]	4,746	12,370	1,569	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	1,404	93,119	[illegible]	5,872	22,331	3,469
[illegible]									
[illegible]	86,676	[illegible]	[illegible]	787	71,717	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	21,595	13,579	1,817		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	6,240			6,240	6,240				

Basin, from San Marcial, N. Mex., to Fort Quitman, Tex., in acres, 1936

Cotton	[illegible]	[illegible] hay	Irri- [illegible] ture	Early [illegible] nuals	[illegible] annuals	[illegible] laneous crops	Double-cropped areas	Cities, towns, [illegible] villages	Land temporarily out of cropping	Grass	Brush	Trees, [illegible]	Pooled [illegible]	River and canal [illegible]	Areas for- irrigated	[illegible] roads, rights- [illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	(10)	(11)	[illegible]	(9a)	(9b)	(9c)	(9d)	[illegible]	(12)	(13)	
[illegible]	[illegible]	[illegible]	[illegible]	3,062	7,199	11,967	394	2,633	14,153	9,902	27,896	32,354	1,126	15,042		5,671	[illegible] phant Butte Reservoir.
[illegible]	[illegible]	[illegible]	731	2,597	6,468	7,380	83	1,846	8,494	5,636	18,958	27,612	[illegible]	13,398		4,311	
[illegible]	[illegible]	4	110	165	731	4,587	311	787	5,659	4,266	8,848	4,712	298	1,644		1,360	
[illegible]	18,059	[illegible]	[illegible]	2,351	5,827	7,061	70	1,708	7,863	5,479	16,853	25,778	819	10,006		4,224	Do.
										1,725	460	17,096	772	2,612		692	[illegible]
										66	2,350	374					
	88	43	306	89	51	253		304	501	419	5,700	1,316		1,190		123	
[illegible]	17,971	61	362	2,265	5,776	6,808	70	[illegible]	7,362	3,269	8,343	6,992	[illegible]	6,204		3,409	
[illegible]	[illegible]	42	[illegible]	573	223	418			445	[illegible]	507	1,431		379			
[illegible]	3,231	44	[illegible]	1,122	2,428	1,480		110	2,129	1,010	2,672	3,628	[illegible]	2,618		494	
47,505	14,740	17	[illegible]	1,143	3,348	5,328	70	[illegible]	5,233	2,259	5,671	3,364		3,586		2,915	
[illegible]	8,625	17	69	198	1,387	2,281	[illegible]	295	3,402	1,856	2,892	1,453		1,653		2,094	
[illegible]	6,115		38	945	1,961	3,047	[illegible]	999	1,831	[illegible]	2,779	1,911		1,933		821	
	283	46	63	[illegible]	641	319	13	138	631	157	2,105	1,834	[illegible]	3,392		87	
	[illegible]	17		129	301	140	[illegible]	15	249	43	[illegible]	486	[illegible]	684		[illegible]	
	119	11		13	61	41		35	134	[illegible]	1,011	165	[illegible]	1,248		16	
	[illegible]	18	[illegible]	79	195	[illegible]			144	[illegible]	37		[illegible]	356		[illegible]	
	11		55	21	[illegible]	61			90	[illegible]	100	[illegible]	[illegible]	[illegible]		15	
	[illegible]		1	[illegible]	5	14	4	88	14	3	[illegible]	[illegible]		321		26	
54,513	17,077	17	199	1,210	3,709	6,128	70	1,523	5,569	2,733	6,933	[illegible]	4	4,077		3,124	
[illegible]	17,727	4	140	465	731	4,587	311	787	5,659	4,266	8,848	4,742	298	1,644		1,360	
7,008	2,337	[illegible]	92	67	361	800		229	336	474	1,262	168	4	491		209	
37,493	14,312	4	48	[illegible]	370	3,787	[illegible]	558	3,506	3,031	4,794	2,228	[illegible]	1,072		932	
41,501	16,649	4	[illegible]	465	731	4,587	[illegible]	787	3,842	3,505	6,056	2,396	[illegible]	1,563		1,141	
12,201	1,078						300		1,819	761	2,792	2,346		81		219	
[illegible]	34,620	65	[illegible]	2,730	6,507	11,395	81	2,191	[illegible]	6,774	14,399	9,388	345	7,767		4,550	
										1,725	460	17,096	772	2,612		692	Do.
866	424	85	[illegible]	[illegible]	274	671		[illegible]	[illegible]	692	8,557	[illegible]		1,569		123	Do.
53,285	17,635	19	[illegible]	1,692	5,553	6,390	70	1,404	6,917	3,062	7,836	5,561	47	5,825		3,409	
14,501	16,649	4	[illegible]	465	731	4,587	11	[illegible]	[illegible]	3,505	6,056	2,396	298	1,563		1,141	[illegible] Paso.
12,201	1,078							[illegible]	1,817	[illegible]	2,792	2,346		81		219	

PART III

SECTION 7.—CONSUMPTIVE USE OF WATER REQUIREMENTS

Before the available water resources of the Upper Rio Grande Basin can be satisfactorily determined, a careful consideration must be given to the present consumptive use requirements for water in the various subbasins. It is desirable that these requirements be related to the present irrigated and other water-consuming acreage in such a way that reliable consumptive use and stream-flow depletion figures can be derived for use in determining the probable draft upon the available water resources when the Basin is completely developed.

Data for determining the use of water by the inflow-outflow method are obtainable only in certain areas of the basin, and are not always equally reliable. Therefore, with the data available it is believed that, considering the entire Upper Basin, the integration method (p. 345) offers the best (or most feasible) means of estimating the present consumptive use requirements for the major subdivisions of the basin.

Application of the integration method produces the estimates appearing in the concluding tables of this report (124 to 129). Hence these estimates are to be understood as representing the present judgment of the Bureau of Agricultural Engineering based not only on its investigations in Upper Rio Grande Basin in 1936 but also, and to an important degree, on its own previous work and the previous work of others in various Western States over a long period of years. Estimates thus based on many studies and long experience, together with the results of the 1936 work in the upper basin, are believed to be a safer guide for studying the irrigation possibilities of the basin than estimates based on the work of only 1 year, especially since the work during that year could not be begun until after the irrigation season was well started.

In arriving at the estimates, no conclusion was involved regarding quantities of water that may be needed in some parts of the upper basin to maintain a proper salt balance in the soil solution of the irrigated areas, the salinity phase of the problem having been delegated to the Bureau of Plant Industry (part IV).

Table 124.—*Units assumed in estimating consumptive water requirements, in acre-feet per acre, San Luis Valley, Colorado and New Mexico*

[illegible]	Irrigated lands			[illegible]			[illegible]			
	[illegible] clover	Native [illegible]	Miscellaneous [illegible]	Grass	Brush	Bosque, trees	Cities, towns, villages	Temporarily out of cropping	Water [illegible]	Bare land
[illegible]										
[illegible]	2.5	1.5	1.5	1.0	[illegible]	3.8	1.5	1.5	3.5	[illegible]
[illegible]	2.5	2.0	1.5	1.5	2.0	3.8	1.5	1.5	3.5	[illegible]
[illegible]	2.5	2.0	1.5	1.5	[illegible]	3.8	1.5	1.5	3.5	[illegible]
[illegible]										
[illegible]	2.0	1.5	1.5	[illegible]	.8	3.5	1.5	1.5	3.3	[illegible]
[illegible]	2.5	2.0	1.5	1.5	1.5	3.8	1.5	1.5	3.5	[illegible]
[illegible]	2.3	1.8	1.5	1.5	1.5	3.8	1.5	1.5	3.5	[illegible]
[illegible]	2.0	[illegible]	1.5	1.0	1.0	[illegible]	1.5	[illegible]	3.5	[illegible]
[illegible]	2.5	2.0	[illegible]	1.5	[illegible]	3.8	1.5	[illegible]	3.5	[illegible]
[illegible]										
[illegible]	2.2	1.5	1.5	1.0	1.0	3.8	1.5	1.5	3.5	[illegible]
[illegible]	2.2	1.5	[illegible]	1.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	1.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 125.—*Estimate of consumptive water requirements in the San Luis Valley, Colo. (including precipitation), based on [illegible] acreage*

Location	Irrigated lands			Native vegetation			Miscellaneous[1]			Total area		
	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre
Closed basin area:												
Saguache County	171, 182	272, 426	[illegible]	223, 678	271, 932	1. 22	35, 978	34, 297	0. 95	430, 838	578, 655	1. 34
Rio Grande County (part)	56, 792	101, 212	1. 78	4, 227	8, 668	2. 05	4, 008	6, 048	1. 51	[illegible]	115, 928	1. 78
Alamosa County (part)	49, 948	[illegible]	2. 04	176, 109	[illegible]	1. 70	11, 503	14, 852	1. 29	237, 560	417, 058	1. 76
Entire area	277, 922	[illegible]	1. 71	404, 014	580, 814	1. 44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Southwest area:												
South Fork, Schraeders, Pinos Creeks and areas above	20, 438	31, 616	1. 55	3, 429	[illegible]	2. 51	2, 823	[illegible]	1. 88	[illegible]	[illegible]	1. 71
Monte Vista Canal, Empire Canal, and small canals	[illegible]	165, 362	1. 95	77, 809	132, 693	1. 71	9, 404	12, 678	1. 35	172, 064	310, 733	1. 81
Alamosa Creek, La Jara Creek, and Terrace Irrigation District	49, 018	88, 409	1. 80	43, 339	71, 113	1. 64	8, 063	10, 823	1. 34	100, 420	170, 345	1. 70
Conejos River and tributaries, San Antonio River, and Los Pinos River	82, 389	132, 871	1. 61	25, 614	45, 105	1. 76	12, 471	[illegible]	[illegible]	120, 474	195, 522	1. 62
Rio Grande Canal, San Luis Canal, and small canals (south closed area)	33, 654	64, 575	1. 92	26, 000	48, 817	1. 88	3, 229	[illegible]	1. 85	62, 883	119, 358	1. 90
Entire area	[illegible]	482, 833	1. 79	176, 191	306, 338	1. 74	35, 990	[illegible]	1. 45	482, 531	[illegible]	1. 74
Southeast area:												
Trinchera Creek and tributaries	16, 847	27, 185	1. 61	73, 173	77, 936	1. 07	5, 955	[illegible]	1. 25	95, 975	112, 557	1. 17
Blanca, Ute, and Sangre de Cristo Creeks	2, 669	4, 390	1. 64	6, 286	11, 412	1. 82	619	1, 063	1. 72	9, 574	16, 865	1. 76
Culebra Creek and Costilla Creek	32, 455	52, 909	1. 63	77, 535	79, 674	1. 03	15, 157	18, 697	1. 23	125, 147	151, 280	1. 21
Entire area	51, 971	84, 484	1. 63	156, 994	169, 022	1. 08	21, 731	27, 196	1. 25	230, 696	280, 702	1. 22
Total or average	[illegible]	1, 042, 947	1. 74	737, 199	1, 056, 174	1. 43	109, 210	[illegible]	1. 23	[illegible]	2, 233, 837	1. 54

[1] Cities, towns, and villages; land temporarily out of cropping; water surfaces—pooled water, river and canal surfaces, and exposed beds; bare land, roads, rights-of-way, etc.

TABLE 126.—*Units assumed in estimating consumptive water requirements, in acre-feet per acre, Colorado-New Mexico State line to San Marcial, N. M.*

Location	Irrigated lands			Native vegetation			Miscellaneous			
	Alfalfa	Native hay, pasture	Miscellaneous	Grass	Brush	Bosque, trees	Cities, towns, villages	Temporarily out of cropping	Water surfaces	Bare land
State line to Rinconada[1]	--		--				--			--
Rinconada to Embudo	3. 5	2. 5	1. 5	2. 5	2. 5	4. 0	2. 0	2. 0	3. 7	1. 0
Embudo to Santa Fe County line	3. 5	2. 5	1. 5	2. 5	2. 5	4. 0	2. 0	2. 0	3. 7	1. 0
Santa Fe County line to Buckman	3. 5	2. 5	1. 5	2. 5	2. 5	4. 0	2. 0	2. 0	3. 7	1. 0
Middle Rio Grande Conservancy District:										
Cochiti Division	4. 0	2. 5	2. 0	2. 5	3. 0	5. 0	2. 0	2. 0	4. 3	1. 0
Albuquerque Division	4. 0	2. 5	2. 0	2. 5	3. 0	[illegible]	2. 0	2. 0	4. 3	1. 0
Belen Division	4. 0	2. 5	2. 0	2. 5	3. 0	5. 0	2. 0	2. 0	4. 3	1. 0
Socorro Division	4. 0	2. 5	2. 0	2. 5	3. 0	5. 2	2. 0	2. 0	4. 5	1. 0
Bosque del Apache Grant	4. 0	2. 5	2. 0	2. 5	3. 5	5. 8	2. 0	2. 0	5. 0	1. 0
Bosque del Apache to San Marcial	4. 0	2. 5	2. 0	2. 5	3. 5	5. 8	2. 0	2. 0	5. 0	1. 0

[1] Canyon section.

TABLE 127.—*Estimate of consumptive water requirements, main stem of Rio Grande, Colorado-New Mexico State line to San Marcial, N. Mex. (including precipitation), based on 1936 acreages*

Location	Irrigated lands			Native vegetation			Miscellaneous[1]			Total area [illegible]		
	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre
State line to Rinconada[2]												
Rinconada to Embudo	191	349	1. 83	31	78	2. 50	[illegible]	[illegible]	3. 46	378	967	2. 56
Embudo to Santa Fe County line	4, 894	10, 037	2. 05	2, 243	6, 615	2. 95	2, 212	6, 608	2. 99	9, 349	23, 260	2. 49
Santa Fe County line to Buckman	[illegible]	1, 823	2. 26	1, 377	5, 030	3. 65	968	3, 102	3. 20	3, 151	9, 955	3. 16
Middle Rio Grande Conservancy District:												
Cochiti Division	5, 208	12, 549	2. 41	11, 232	40, 756	3. 63	2, 999	8, 611	2. 87	19, 439	61, 916	3. 19
Albuquerque Division	22, 819	61, 608	2. 70	23, 495	81, 322	3. 46	11, 813	[illegible]	3. 04	58, 127	178, 832	3. 08
Belen Division	23, 895	65, 188	2. 73	[illegible]	123, 322	3. 02	12, 355	36, 421	[illegible]	77, 044	[illegible]	2. 92
Socorro Division	7, 237	18, 124	2. 50	14, 880	58, 899	[illegible]	[illegible]	40, 156	3. 67	33, 072	117, 179	3. 54
Bosque del Apache Grant				10, 164	56, 364	5. 55	[illegible]	10, 299	4. 26	12, 583	66, 663	5. 30
Bosque del Apache to San Marcial	[illegible]	2, 539	2. 76	2, 617	14, 137	[illegible]	1, 275	[illegible]	4. 10	4, 811	21, 909	4. 55
Total or average	65, 969	172, 217	2. 61	106, 833	386, 523	3. 62	45, 152	146, 872	3. 25	217, 954	705, 612	3. 24

[1] Cities, towns, and villages; land temporarily out of cropping; water surfaces—pooled water, river and canal surfaces, and exposed [illegible]
[2] Canyon section.

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Brush	[illegible] trees	Cities, [illegible]	Temporarily out of [illegible]	Water surfaces	[illegible]
[illegible]					[illegible]	[illegible]	[illegible]			[illegible]	[illegible]
[illegible]		4.0							2.0		
[illegible]		4.0							2.0		
[illegible]	2.5	4.0							2.0	4.5	
[illegible]	2.5	4.2	2.5	2.0	2.5	3.0	4.8	2.0		4.5	
[illegible]									2.5	1.5	

[1] Results of Bureau of Plant Industry salinity studies were not available when these estimates were made. Part IV

[illegible] *precipitation), based on 1936 acreages*

[illegible]	Irrigated lands			Native [illegible]			Miscellaneous [2]			Total area mapped		
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Acre-feet [illegible]	[illegible]	[illegible]	Acre-feet [illegible]	[illegible]	[illegible]	[illegible]
[illegible]	—	—	—	[illegible]	[illegible]	5.26	[2] 20,750	110,873	[illegible]	[2] 42,821	225,[illegible]	5.27
[illegible]	830	2,011	2.42	7,435	[illegible]	3.48	2,118	7,066	3.34	10,383	34,912	3.37
[illegible]	15,206	40,346	[illegible]	7,310	[illegible]	3.82	5,398	16,847	3.12	27,914	85,118	3.05
[illegible]	82,923	227,365	[illegible]	13,198	43,199	3.27	14,297	34,745	2.43	110,418	305,299	[illegible]
[illegible]	[illegible]	163,105	2.89	10,053	[illegible]	3.25	[4] 6,362	14,927	2.35	[4] 72,858	210,686	[illegible]
[illegible]	13,579	35,631	[illegible]	5,899	[illegible]	3.83	2,117	5,061	2.39	21,595	63,279	[illegible]
[illegible]	168,961	468,458	2.77	65,966	267,039	4.05	[illegible]	189,476	3.71	[2,4] 285,969	924,973	3.23

[illegible] land, roads, rights-of-way, etc.

[illegible]

[illegible]

NOTE.—Results of Bureau of Plant Industry salinity studies were not available when estimates were made. Part IV.)

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PART IV
QUALITY OF WATER IN UPPER RIO GRANDE BASIN

Report of the United States Bureau of Plant Industry [1]

Contents

[1] [illegible]

Tables

PART IV
PREFACE

As originally prepared the report on the quality of the water of the Rio Grande Basin consisted of two parts; the analytical data and the interpretive report. The analytical data were assembled first in a volume of 296 pages, of which 70 copies were reproduced by multilith in January 1937 and distributed to cooperators. The interpretive report was prepared subsequently and with the expectation that the two reports would be published together. It was later decided to publish the interpretive report as a part of the report of the Rio Grande Joint Investigation and to publish the Analytical Data as Water Supply Paper No. 839 of the United States Geological Survey.

The introductory statement of the analytical data is reproduced below because it contains information needful to an understanding of the terms and tables of this report.

Introduction

The analytical data of this report have been obtained in part from field investigations conducted in 1936 by the United States Geological Survey and in 1935 and 1936 by the State of Texas, and in part from an investigation conducted since 1930 by the United States Bureau of Plant Industry in cooperation with the State engineer of Colorado, the United States Geological Survey, the United States section of the International Boundary Commission United States and Mexico, and the United States Bureau of Reclamation. In general the authority for the data is shown in the table headings or with the descriptive statements.

The locations from which the water samples have been obtained are described in the text that accompanies the tables of analyses. For the most part these descriptions are based on surveys of the type used by the General Land Office. For areas that have not been surveyed by the General Land Office, a similar net of sections and townships has been superimposed on the maps of this report. For convenience of cross-reference between this section of the report and the maps, the descriptive list includes an index number for each location. In this hyphenated index number the first number refers to the section, the second to the township, and the third to the range.

The tables of analytical data fall into three major groups as follows:

Group I. Tables that relate to conditions along the main stream of the Rio Grande as it has been sampled at nine gaging stations from Del Norte, Colo., to Fort Quitman, Tex., for several years past.

Group II. Tables that relate to conductance determinations on series of samples from a large number of stations representing both surface and ground waters. Mostly collected in 1936.

Group III. Tables that report the detailed analyses of samples from a smaller number of stations selected from among those for which conductance determinations have been made but including also some stations for which no additional conductance determinations have been made.

The tables of groups II and III are further subdivided so as to conform to the natural subdivisions of the drainage basin as follows:

1. The San Luis Valley comprises that portion of the drainage basin tributary to the main stream above the southern boundary of the State of Colorado.
2. The Middle Valley comprises that portion of the drainage basin tributary to the main stream between the southern boundary of the State of Colorado and the San Marcial, N. M., gaging station.
3. The Elephant Butte project is the designation used for that portion of the drainage basin between the San Marcial gaging station and the Fort Quitman, Tex., gaging station.

It should be noted that certain surface water stations in the San Juan drainage basin, and some stations on tributaries of the Rio Grande that enter the main stream below San Marcial, have been included in the tables for the Middle Valley.

For each of the subdivisions of the drainage basin there are tables for surface waters and for ground waters. The demarcation between these two sources is not always clear. Surface waters include not only all natural streams and irrigation canals diverted from them but also drains which latter are largely fed by ground water. Ground waters include samples from wells whether shallow (subsoil waters) or deep (underground waters). With ground waters have been included samples from springs when taken at the spring and samples from certain small ponds in the San Luis Valley where the water appears to be derived, at least in part, from artesian wells.

Methods of Analysis

In general the methods of analysis used in this investigation have been those adopted for use with irrigation waters by the Rubidoux Laboratory of the United States Bureau of Plant Industry.[1]

[1] U. S. Department of Agriculture, Bureau of Plant Industry. Methods of Analysis used in the Rubidoux Laboratory, Riverside, Calif., 11 pp. Revised Mar. 20, 1933 (Mimeographed.)

The tabulated analyses include some or all of the following determinations:

1. Specific electrical conductance, expressed as $K \times 10^5$ at 25° C.
2. Total dissolved solids, expressed as tons per acre-foot of water.
3. Hydrogen-ion concentration, expressed as pH.
4. Calcium (Ca), expressed as milligram equivalents per liter.
5. Magnesium (Mg), expressed as milligram equivalents per liter.
6. Sodium (Na), expressed as milligram equivalents per liter.

NOTE.—In some of the analyses the values reported for sodium are the results of the direct determination of that constituent, in other analyses the values have been obtained by difference, i. e., by subtracting the sum of the calcium and magnesium from the sum of the anions, bicarbonate, sulphate, chloride, and nitrate, all these constituents being expressed as milligram equivalents per liter.

7. Potassium (K), expressed as milligram equivalents per liter.
8. Carbonate (CO_3), expressed as milligram equivalents per liter.
9. Bicarbonate (HCO_3), expressed as milligram equivalents per liter.

NOTE.—Because the normal carbonate (CO_3) occurs infrequently in irrigation water it is not reported separately in most of the tables. Where it is reported by the analyst the values are added to the values for the bicarbonate in the tables.

10. Sulphate (SO_4), expressed as milligram equivalents per liter.
11. Chloride (Cl), expressed as milligram equivalents per liter.
12. Nitrate (NO_3), expressed as milligram equivalents per liter.
13. Silica (SiO_2), expressed as parts per million.
14. Boron (B), expressed as parts per million.

NOTE.—In general, the boron values reported in the tables of group I were determined at the Rubidoux Laboratory by the method of electrometric titration, while those in the tables of group III were determined at the Water Resources Laboratory of the United States Geological Survey by the colorimetric, turmeric method.

15. Fluoride (F), expressed as parts per million.

NOTE.—In general, the fluoride values reported in the tables of group III were determined at the Water Resources Laboratory of the United States Geological Survey by the ferric thiocyanate colorimetric method.

16. Silt (total suspended matter), expressed as tons per acre-foot of water.

NOTE.—Since the chief objective of the investigations here reported has been to learn the conditions of salinity in the area, only incidental consideration has been given to the silt burden of the streams. In collecting the water samples no serious effort has been made to obtain samples that would adequately represent the silt conditions and consequently the data on silt content here reported should not be taken as the best obtainable.

Computations and Interpretations

The tables of detailed analyses in groups I and III generally include one column headed percent sodium and another headed percent chloride. The values reported in these columns are derived from the analytical data reported in the tables. The values for percent sodium are obtained by dividing the sum of the values for all the cations, calcium, magnesium, and sodium (including potassium if reported) into the values for sodium (and potassium) multiplied by 100; i. e.—

$$\frac{(Na+K)\times 100}{Ca+Mg+Na+K} = \text{percent sodium}$$

Similarly the values for percent chloride are obtained by the formula

$$\frac{(Cl+NO_3)\times 100}{HCO_3+SO_4+Cl+NO_3} = \text{percent chloride}$$

The significance of the derived value, percent sodium, is due to the role of the basic or cation constituents in the exchange reactions that occur when water containing dissolved salts comes in contact with the soil. The use in irrigation of waters containing high sodium percentages tends to impair the physical condition of the soil while the use of waters of low sodium percentages tends to maintain good physical condition or to improve poor physical condition where that condition has been caused by the deflocculation of the clay fraction.

The significance of the value, percent chloride, is less directly agricultural. It is probably true that with equal concentrations of total dissolved solids the water having the higher chloride percentage would be the less desirable because the chloride constituent is regarded as more toxic than the sulphate or bicarbonate. Probably the chief value of reporting the chloride percentage is that together with the percent sodium it indicates the general character of the water involved or the degree or relationship between waters from different sources.

The fact that the conductance (specific electrical conductance, $K \times 10^5$ at 25° C.) of water samples is extensively used in this report as a measure of the concentration of the dissolved salts, warrants an explanation of the meaning of the term and of the significance of the measurement. Speaking technically, the conductance of a water sample is the reciprocal of its electrical resistance. The electrical resistance is what is actually measured. The resistance, measured in ohms, is determined by means of a Wheatstone bridge and a suitable vessel in which two platinum electrodes are immersed in the water to be tested. With suitable means of temperature control or of compensating for differences of temperature of the water, the electrical resistance may be measured and the result of this measurement may be computed into the equivalent reciprocal of the resistance, which is the conductance, and the value stated as of a definite temperature. Because the measured resistance is more than 1 ohm and often several hundred ohms, the reciprocal is a decimal number. The letter K is the conventional symbol for electrical conductance; when it is followed by the symbol "$\times 10^5$" it means that the decimal point has been moved 5 places to the right. The expression "at 25° C." means that the resistance was determined with the solution at 25° centigrade or that the resistance reading was compensated to its equivalent at that temperature.

Conductance is a relative measure of the concentration of total dissolved salts, or more specifically, of the total dissolved electrolytes in the water sample. It is a measure of the ionic concentration and because the various ions have different weights when measured gravimetrically the results of a conductance determination may not be converted precisely into a gravimetric measure of concentration such as parts per million or tons per acre-foot. There is, however, an approximate relationship between the two measurements, when applied to the systems of mixed salts that occur in natural waters. This relationship is such that, in general, natural waters having a conductance of 100 have a concentration of total dissolved salts of 0.90 to 1.0 ton per acre-foot. With any group of water samples of the same type or from the same general source, it becomes possible to make a close approximation of the gravimetric equivalent of a conductance value by determining both values for a number of representative samples.

In this report conductance determinations have been given for a large number of samples in the tables of group II. In the tables of groups I and III detailed analyses are reported. These detailed analyses include the values both for conductance and for total dissolved solids. When it is desired to convert the conductance values found in the tables of group II into gravimetric equivalents it is suggested that recourse be had to the tables of detailed analyses where samples similar in source or type may be found and a conversion factor obtained by taking the mean of the ratios between the conductance and gravimetric values for a number of such samples.

Water analysts usually report gravimetric concentrations of total salts or total dissolved solids as parts per million. In the present report such concentrations are reported as tons per acre-foot. The conversion from one scale to the other may be made by the factor 0.00136. In other words, parts per million is multiplied by 0.00136 or 136×10^{-5} to obtain the value, tons per acre-foot. Similarly the silt content of water samples is usually reported by analysts as percentage or parts per hundred. In the tables of this report, when the silt constituent is included, it is expressed as tons per acre-foot by using the conversion factor 13.6. These conversion factors are derived from the assumption that an acre-foot of water weighs 2.72 million pounds.

In case it is desired to convert the values here reported as milligram equivalents per liter into the scale of parts per million (milligrams per liter) that may be done by the use of appropriate factors. These factors are the combining weights of the several ions related to hydrogen as 1. The factors conventionally used to multiply the milligram equivalent values are: for calcium, 20.0; for magnesium, 12.15; for sodium, 23.0; for potassium, 39.0; for carbonate, 30.5; for bicarbonate, 61.0; for sulphate, 48.0; for chloride, 35.5, and for nitrate, 62.0. If it is desired to compute the "total hardness" of a water sample to be expressed as the equivalent of calcium carbonate in parts per million, this may be done by taking the sum of the milligram equivalents of calcium and magnesium multiplied by 50.

PART IV

SECTION 1.—INTRODUCTION AND SUMMARY

The present report is based on an investigation conducted during the summer of 1936 under the auspices of the Rio Grande Joint Investigation together with certain cooperative investigations conducted since 1930 by the United States Bureau of Plant Industry; the United States Bureau of Reclamation; the United States Geological Survey; the United States section of the International Boundary Commission, United States and Mexico; and the State engineer of Colorado. This latter cooperative investigation was confined chiefly to conditions along the main stream while the investigations of 1936 included also the tributary streams and the ground waters in the irrigated areas of the basin.

The analytical data of this report include also certain analyses of water samples published in Water Supply Paper 240, United States Geological Survey, copies of which are not now readily obtainable, and certain analyses of water samples from stations in Elephant Butte project made by the United States Bureau of Reclamation but not hitherto published. Certain other analyses, of samples collected at the San Marcial and Courchesne (El Paso) stations 1905–7, are reported in Water Supply Paper 274, United States Geological Survey, and are not here included. Water Bulletins Nos. 1 to 5, published by the International Boundary Commission, 1931 to 1935, also include certain analytical data, most but not all of which are here included. Finally there are some analyses of water samples, collected from the Rio Grande near Las Cruces, N. Mex., in 1893–94, published in Bulletin 30 of New Mexico College of Agriculture and Mechanic Arts, June 1900, that are not here included because of uncertainty as to the discharge conditions represented.

The data of this investigation show that the Rio Grande collects annually from its headwaters in the high mountains of southern Colorado approximately a half million acre-feet of water of very low salinity. Some of this water is diverted for irrigation use in the San Luis Valley of Colorado and as the river leaves that valley it carries, in addition to its residual channel flow, the discharge of drains from the irrigated land of the San Luis Valley together with the contributions from several tributary streams that originate in the mountains surrounding the valley. The salinity of these valley contributions is such as to increase materially the concentration of the water as the river leaves the San Luis Valley and the State of Colorado, but this concentration is still low as compared with conditions found farther down the stream.

As it leaves the San Luis Valley the river enters a canyon section in northern New Mexico in which it is joined by several tributaries which increase its volume of discharge to somewhat less than a million acre-feet annually but do not change its salt concentration materially. Below this canyon section water is diverted at successive stations to irrigate lands contiguous to the river channel above and below Albuquerque, N. Mex. In this section, known as the Middle Valley, the river is joined by several tributaries chiefly from the west and also it regains drainage water from the irrigated lands. The net effect of these diversions and contributions during the period covered by this investigation has been to diminish slightly the volume of river water annually leaving Middle Valley as compared with the volume that enters it at its upper end but to increase its concentration about threefold.

The stream waters leaving the Middle Valley are collected in Elephant Butte Reservoir the storage capacity of which is approximately 2.5 million acre-feet, or about three times the annual discharge of the stream at this point. Water is released from this reservoir chiefly during the summer months, as it is required for irrigation on the lands of the Elephant Butte project which lie along the stream for 200 miles.

During the period of the investigation here reported, 1931 to 1936, the mean annual volume of water released from Elephant Butte Reservoir has been slightly more than 750,000 acre-feet. This water is practically all diverted from the stream channel for irrigation use, some of it being allocated for use in Mexico. There are no important tributary contributions between Elephant Butte Reservoir and the lower end of the El Paso Valley but the drainage waters from the upper divisions are returned to the stream channel and rediverted to the lower divisions.

The discharge of the stream at the Fort Quitman gaging station, the lower limit of the basin covered by this investigation, consists largely of drainage water returned to the stream from the lower divisions. Its mean annual volume for the period of this investigation, 1931–36, has been about 175,000 acre-feet, as compared with 750,000 acre-feet annually released from Elephant Butte Reservoir. Its mean concentration at the Fort Quitman station, 2.75 tons of dissolved solids per acre-feet, is more than three times as high as that of the water released from Elephant Butte Reservoir.

The conditions of salinity found in the ground waters of areas contiguous to the main stream are in general

similar to those found in the stream itself. In the present investigation more attention has been given to the quality of the shallow or subsoil waters for the reason that those are thought to be more closely related to irrigation conditions. Except in the San Luis Valley practically no use is made of the deeper ground waters for irrigation. The deeper ground waters of the San Luis Valley as obtained through artesian wells were formerly used to some extent for irrigation. Some of these artesian waters contain dissolved salts that differ strikingly in composition from the surface waters of that area. They are characteristically "soft" waters, i. e., they have high sodium percentages and their use for irrigation has been injurious to the soil. This is not true for all of the artesian waters of the San Luis Valley but only of the waters obtained in certain areas.

In summarizing the data obtained by this investigation an attempt has been made to estimate the quantities of total dissolved solids and of each of the more important constituents carried by the stream past each of the principal gaging stations. These estimates show not only that the quantities of the total dissolved solids passing each station differ greatly but also that the quantities of each constituent differ even more, so that the composition of the dissolved solids changes appreciably from station to station. Probably the most striking of these changes is the progressive increase in the quantity of the chloride constituent in the down-stream direction. For 1936 the only year for which data are available for all nine stations the quantity of chloride increased from 2,800 tons at the Del Norte station to 137,000 tons at the Fort Quitman station. The increase in sodium, from 4,400 tons to 92,000 tons was also large.

It seems obvious that the increasing quantities of these salt constituents reported for the successive stations may be due in part at least to the contributions from tributary streams. But this source of origin can hardly be invoked to explain large increases that occur between stations where no tributaries join the stream, as for example within divisions of the Elephant Butte project. In order to explain the phenomenon of the local gains of the chloride constituent, associated as it is with local losses of other constituents, the theory of displacement is proposed. According to this theory it is suggested that the ground water held in the sediment-filled valleys of the river, as in the El Paso Valley, may be highly concentrated in respect to chloride and that the irrigation water percolating from the distribution system displaces some of this saline ground water which in turn passes out through the drains. The agricultural implications of this theory are referred to briefly

Scope of Report

This report deals with the quality of the water, both surface and underground, in the drainage basin of the Rio Grande above Fort Quitman, Tex. The constituents of the water here reported are those that relate to its agricultural use rather than to its use for domestic or industrial purposes. The area involved includes 34,450 square miles, of which all but 834 square miles is in the United States, the remainder being in Mexico. Within this area water samples have been obtained for analysis from 1,215 stations within the basin and from 7 stations in the basin of San Juan River, a tributary of the Colorado River, making a total of 1,222 stations covered by the report.

For the purpose of this investigation the drainage basin above Fort Quitman has been divided into three areas:

(1) The San Luis Valley, Colo.;

(2) The Middle Valley, N. Mex., extending from the Colorado State line to the San Marcial gaging station and including the stations in the San Juan [2] basin; and

(3) The Elephant Butte project, New Mexico and Texas, including the area below San Marcial and above Fort Quitman gaging station.

According to these subdivisions there are 486 sampling stations in the San Luis Valley, 621 in the Middle Valley, and 115 in the Elephant Butte project. For the water samples obtained from these stations two kinds of analyses were made:

(1) A determination of the concentration of dissolved salts either by electrical conductance or by evaporating a filtered aliquot and weighing the dried residue; and

(2) A detailed analysis by which, in addition to the concentration, a number of the more important constituents were determined.

The present report gives the results of 12,074 analyses, of which 9,564 are of concentration only and 2,510 are detailed analyses.

In respect to the three subdivisions of the basin, the number and kind of analyses are as follows:

For the 486 stations in the San Luis Valley there are 1,552 analyses for concentration only and 283 detailed analyses—a total of 1,835.

For the 621 stations in the Middle Valley, including the San Juan stations, there are 4,481 analyses for concentration only and 739 detailed analyses—a total of 5,220.

For the 115 stations of the Elephant Butte project there are 3,531 analyses for concentration only and 1,488 detailed analyses—a total of 5,019.

[2] In connection with the present investigation it was deemed advisable to include the examination of a few water samples from the headwaters of San Juan River, a tributary of the Colorado, because of the possibility that some of these waters might be diverted into the adjacent basin of the Rio Grande. The locations of these samples and their analyses are given on pp. [illegible] and [illegible] of the analytical data. These samples were all of low salinity, with conductances ranging from [illegible] to [illegible] and with low sodium percentages, ranging from 17 to 34. In general they are similar in quality to those collected from the upper tributaries of the Rio Grande that discharge into the San Luis Valley.

PART IV

SECTION 2.—THE HEADWATERS OF THE RIO GRANDE

The headwaters of the Rio Grande come from the eastern crest of the Continental Divide in the eastern part of San Juan County, Colo. Tributaries join it from the high mountains of Hinsdale and Mineral Counties as it makes its tortuous way eastward to enter the San Luis Valley in Rio Grande County some 65 miles east of its head. This part of the basin above the Del Norte gaging station comprises 1,320 square miles of rough topography and all above 8,000 feet in elevation. The precipitation collected in this area, largely winter snows and early spring rains, yields annually 707,000 acre-feet of water, or approximately 0.72 acre-foot per acre of drainage area. About 64 percent of this volume passes the Del Norte gaging station during the 3 months, May, June and July.

In the present investigation, 1936, water samples were obtained from eight stations on the main stream and its tributaries above Del Norte. From three of these stations, viz, the main stream at Wason, South Fork, and Pinos Creek, samples were taken periodically during the summer for conductance determinations. From the other five stations individual samples were taken for partially detailed analyses. These samples all show that these headwaters are remarkably low in dissolved salts. The conductances range from 4.6 to 12.8; the latter equivalent to 0.13 ton of total dissolved solids per acre-foot of water.

During 1936 the volume of water passing the Del Norte gaging station was 472,300 acre-feet, or approximately two-thirds of the normal flow for the 46 years of record. This discharge as represented by 47 samples, taken at approximately weekly intervals, ranged in conductance from 5.6 in June to 16.0 in January with a weighted mean for the year of 8.46. The weighted-mean total dissolved solids was 0.11 ton per acre-foot. These values show that the headwaters of the river are remarkably pure, and the detailed analyses show that the chief dissolved constituents are calcium bicarbonate and silica.

From Del Norte, where the river enters the San Luis Valley near the center of its west side, the stream flows southeast and south to cross the State line into New Mexico at a point about 30 miles east and 40 miles south of Del Norte. In this section the stream is joined by several tributaries that drain both the east and west sides of the south end of the San Luis Valley. The streams that drain the slopes of the northern half of the valley yield little water and that is mostly dissipated locally by evaporation from the valley floor, which is somewhat lower than the channel of the Rio Grande.

The drainage area of the Rio Grande tributary to the section of the stream between Del Norte and the New Mexico State line comprises approximately 3,500 square miles exclusive of closed basins. This area includes the major portion of the half million acres of irrigated land in the San Luis Valley. Unlike the uppermost section of the drainage basin this area makes no addition to the stream flow. On the contrary, it consumes more water than it contributes. The mean annual discharge, for the 46 year period, is 707,000 acre-feet at Del Norte, while at the Lobatos station just above the State line the mean annual discharge is 550,000 acre-feet. During 1936 the difference was even greater, 472,300 acre-feet at Del Norte and 281,000 acre-feet at Lobatos.

Water is diverted from the main stream and from its tributaries in this section for irrigation in the San Luis Valley. Not all the stream flow is diverted and some of the diverted water returns to the stream as drainage from the irrigated lands. The effect of these drainage returns is to increase the salinity of water of the main stream. In 1936 its conductance at the Lobatos station, based on 50 consecutive samples, ranged from 13.3 in April to 70.9 during a period of low flow in July. The weighted mean conductance for that station for the year as shown in table 17 was 26.5 as compared with 8.46 at Del Norte. The total dissolved solids increased between the two stations from 0.11 to 0.265 ton per acre-foot.

The conditions of salinity found in the tributary streams in this section of the basin are discussed in the next chapter. It may be noted here that the effect on the main stream of these tributary contributions is not only to increase the concentration of its dissolved salts but also to change the composition of these salts.

The diversion and use of water for irrigation in the San Luis Valley appears to have an appreciable regulatory effect on the regimen of the stream between the Del Norte and Lobatos stations in addition to diminishing the total flow and increasing the concentration of the dissolved salts. At the Del Norte station in 1936 the discharge during the summer months, April to September, inclusive, comprised 85 percent of the total annual discharge, leaving only 15 percent for the 6 months, October to March. At the Lobatos station the corresponding percentages were 60 and 40.

PART IV
SECTION 3.—THE SAN LUIS VALLEY

Surface Waters

San Luis Valley lies near the middle of the southern part of Colorado. It is bounded on the west by the main range of the Rocky Mountains and on the east by the Sangre de Cristo Mountains. Peaks in both ranges of mountains extend above 13,000 feet. The Valley extends northward from the southern State line about 90 miles to Villa Grove and the greatest width of its gently sloping plain is about 45 miles. Its elevation is about 7,500 feet at its lowest point with arable land rising to 8,000 feet. The Rio Grande, which enters the Valley near the center of the west side, has deposited a delta cone that extends into the valley trough and cuts off the free outflow of the streams that discharge into the northern half of the Valley so that their waters are dissipated locally by evaporation and transpiration.

In the present investigation, water samples have been taken from six of the streams that discharge into the northern part of the valley from the Sangre de Cristo Mountains on the east, from Crestone to Sand Creek. The conductance of these is very low, ranging from 4.6 to 10.4. The dissolved constituents are chiefly silica and calcium bicarbonate, so that these waters probably contribute very little salinity to the valley lands. Of the streams entering the northern part of the Valley from the west, four have been sampled, from Kerber to La Garita Creeks. The conductances of these samples range higher than those from the streams on the east, from 9.1 to 64.1, with the highest conductance found in Kerber Creek. Detailed analyses of samples from Saguache and Carnero Creeks show that here also the chief dissolved constituents are silica and calcium bicarbonate. These findings indicate that currently the streams discharging into the northern part of the San Luis Valley are contributing very little potential salinity to the Valley lands.

In the southern part of the Valley the drainage from the east is collected by two streams that discharge into the Rio Grande, Trinchera Creek and Culebra Creek. On Trinchera Creek there are two small reservoirs, one at Mountain Home, above the 8,000-foot contour line and above any important diversion, and Smith Reservoir at the junction of Ute and Sangre de Cristo Creeks with Trinchera Creek. Samples taken from four stations on Trinchera and Ute Creeks above the 8,000-foot contour line show conductances ranging from 7.7 to 21.1. Sangre de Cristo Creek sampled at two stations above Smith Reservoir shows conductances ranging from 23.6 to 40.2; while Trinchera Creek sampled at a station below Smith Reservoir range from 24.5 to 36.1. Detailed analyses of samples from this station show that calcium bicarbonate is the chief constituent of the dissolved solids. On Culebra Creek the waters from some of the upper tributaries are stored in Sanchez Reservoir. The stream has been sampled at one station near the town of San Luis, 5 miles below the reservoir. These samples showed conductances ranging from 9.2 to 25.3, and a detailed analysis shows that here also the dissolved solids are chiefly silica and calcium bicarbonate. No samples were taken from the lower sections of Trinchera and Culebra Creeks as they join the Rio Grande.

On the west side of the southern part of the San Luis Valley the natural drainage and much of the artificial drainage from the irrigated land is collected by three streams that empty into the Rio Grande. These are Alamosa, La Jara, and Conejos Rivers. The upper tributaries of Alamosa River are collected in Terrace Reservoir, above any important diversions. Water samples from a station just below this reservoir show conductances ranging from 12.0 to 24.2. One sample taken lower down the stream but above any irrigation drain had a conductance of 10.6. On Rock Creek, a tributary of the Alamosa, samples were taken from four stations. One of these stations located above the 8,000-foot contour line showed conductances ranging from 6.8 to 13.1. Spring Creek is a tributary of Rock Creek that originates below Monte Vista canal. Samples from a station near its source showed conductances of 24 to 38. In its lower section, Rock Creek collects drainage from irrigated land and samples from two stations a few miles above its mouth showed conductances ranging from 46.3 to 106, and detailed analyses of samples from these stations show the presence of appreciable quantities of sulphate, chloride, and sodium.

La Jara River has been sampled at three stations. At the upper one of these, located above the irrigated land, the conductances ranged from 10.6 to 16.9. At Diamond Springs which, like Spring Creek, originates below an irrigation ditch, the conductances were 32.9 and 36.3. At a station on the main stream farther

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down near Sanford the conductance range was 24.6 to 42.4, and a detailed analysis showed appreciable quantities of sodium and sulphate.

On Conejos River and its tributaries samples were obtained from seven stations. From three of those stations on the main stream above the irrigated land and from one station on Los Pinos Creek, also above irrigation, the conductances were all very low, ranging from 4.6 to 11.4. One sample from the main stream in the irrigated area north of Antonito had a conductance of 6.0. Samples from a station on Rio San Antonio, near Manassa, where it joins the Conejos, had conductances of 11.1 and 22.2, while samples from a station on the main stream near its junction with the Rio Grande had conductances ranging from 14.8 to 23.4.

These data show that of the five streams in the San Luis Valley that discharge into the Rio Grande, all carrying some drainage from the irrigated lands, the salinity is low in all except in Rock Creek, and it is not excessively high even in the lower section of that stream.

In addition to the surface waters of natural streams the present investigation included the sampling of a number of drains on the west side of the San Luis Valley. On the delta cone north of the Rio Grande where some of the cropped land has a very permeable subsoil, the method of irrigation is to fill the subsoil with water by percolation from field ditches, controlling the elevation of the water in the subsoil by means of a system of outlet ditches or shallow open drains. In the area between the Rio Grande, north of Monte Vista, and the town of Center, this system of irrigation is extensively used. This area is served by the Rio Grande drain. Samples from two stations on this drain show conductances ranging from 27.5 to 56.9. The area north of Center is served by the Gibson drain which has been sampled at two stations, where the conductances ranged from 29.6 to 36.6. The area lying to the east of Center, toward the Valley trough, is served by the San Luis Valley irrigation district drain which discharges into San Luis Lake. This drainage system has been sampled at six stations with conductances ranging from 39.3 to 67.8. Samples have been taken also from two stations on San Luis Lake where conductances ranging from 63.9 to 108 were found. Detailed analyses of samples from the lake show that the chief salt constituents are sodium and magnesium combined with bicarbonate, sulphate, and chloride. Fluoride also was reported for these samples in concentration of approximately 1.5 p. p. m. The Hall drain in the northern tip of the valley was sampled at one station with conductances of 49.3 and 61.1.

In that portion of the Valley south and west of the Rio Grande samples have been taken from seven stations on five drains. At two stations on the Bowen drain the conductances ranged from 56.4 to 98.1, being slightly higher from the station near the drain outlet. Samples from one station on Waverly drain ranged from 96 to 186. From two stations on Carmel drain the range was 85.5 to 161. Morgan drain, sampled at one station, gave the highest conductances reported, ranging from 126 to 310; while those from one station on La Jara drain ranged from 68.6 to 89.7.

The data in respect to the surface waters of San Luis Valley show that the streams flowing into the Valley contain relatively very little dissolved material. The water leaving the Valley through the Rio Grande seldom contains more than half a ton of dissolved solids per acre-foot and frequently less than 500 pounds per acre-foot. The water in the drains north of the river is also of relatively low salinity. In some of the drains south of the river the salinity is relatively high and it is doubtless from this area that most of the salt is derived that the river carries out of the Valley.

Ground Waters

The San Luis Valley is a sediment-filled depression between the Rocky Mountains on the west and the Sangre de Cristo Mountains on the east. In dimensions it is approximately 90 miles from north to south and about 40 miles from east to west. The present surface slopes gently from both sides to the Valley trough which, at its lowest point is about 7,500 feet above sea level. The sediments of the Valley fill are apparently saturated with water. The surface of the saturated zone is generally within a few feet of the ground surface, and through much of the lower area the deeper water is under pressure from the higher intake areas at the sides of the Valley so that flowing artesian wells are common.

In the present investigation concerning the quality of the ground waters of the Valley there were two objectives: (1) to measure the concentration of the total dissolved salts, and (2) to ascertain the composition of these salts. The data bearing on the first objective are reported on pages 66 to 99 of the Analytical Data. The results of the detailed analyses are reported on pages 198 to 219 of that report. In both groups the data are given in respect to surface areas without attempting to make a definite segregation between shallow or subsoil waters and the deeper waters. Samples were taken from 280 shallow or observation wells, often only 6 to 8 feet deep. These samples manifestly represent only the subsoil water. Among the deeper wells, numbering 121, there is wide range of depth. Some of these were dug wells of various depths from 15 feet to 80 feet or more, but not tightly cased and probably drawing water from each permeable stratum penetrated. Even among the drilled wells it

is not always certain that the water comes chiefly from near the bottom of the well because some of them are not tightly cased to the full depth. In addition to the wells, samples were taken from 10 springs and from 1 small lake, making a total of 412 stations.

In collecting the data in respect to concentration only the aim was to take three samples, a month or more apart, from each well. It was known that such consecutive samples, particularly from shallow wells, might show different concentrations as local conditions changed during the season. Sometimes these differences are so great that it becomes difficult to decide on an acceptable single value for the concentration of the water from a given well. It is possible that there may have been occasional errors in recording the location data for certain samples which might explain some of the discrepancies. However, it is known from similar investigations elsewhere that pronounced changes do occur in the concentration of consecutive samples from the same shallow well. Such changes are uncommon in consecutive samples from deep wells and from many of these only individual samples are reported.

In the present interpretation of the conductance data from the wells of the San Luis Valley the location of each well was spotted on a map of the area, with an indication as to whether the well was regarded as shallow or deep. The conductance data for each well were then examined and a single value taken that seemed best to represent the conditions of concentration at that well.

It was found that for the whole area the conductance values ranged from less than 20 to more than 1,000. For convenience of consideration, an arbitrary grouping was established involving nine ranges of concentration as measured by conductance. The accepted concentration value for each well was then indicated as a part of its location symbol so that the map showed the approximate concentration of the water obtained from it.

The nine groups are listed in table 1 with the conductance limits of each group, together with the number of locations that fall into each group. It will be seen that of 411 stations sampled the waters of 150 of them had conductances of less than 50, while there were 123 stations from which the waters had conductances ranging from 50 to 100. Thus 273 out of 411 stations gave samples with conductances ranging under 100. At the other extreme there were 35 stations, including a small lake, not listed in the table, from which the conductances ranged above 400. The concentration of dissolved salts is generally less in the water from deep wells than from the shallow ones, yet 11 of the deep wells gave conductances higher than 150.

The ground waters with the lowest salinity occur on both sides of the Valley. On the west side most of the wells, both shallow and deep, north of the Rio Grande and west of range 9, fall into group 1 with conductances less than 50. On the west side, south of the river, there is a narrow band of water of low salinity mostly from deep wells extending southeast through ranges 8 and 9 to the south end of the Valley. Along the east side of the Valley there is a narrow band of ground water of low salinity extending southeastward from the southwest corner of range 11, township 44, to range 12, township 37. Between these two sides the ground water is generally more saline, though not universally so.

TABLE 1.—*Ground waters of the San Luis Valley, Colo., showing the number of locations sampled and the number of samples that fall into each of nine groups of concentration range*

Group and range of concentration as measured by conductance ($K \times 10^5$ at 25° C.)	Springs	Shallow wells	Deep wells	Total locations
1. Less than 50	7	46	97	150
2. 50 to 100	1	112	10	123
3. 100 to 150		47	3	50
4. 150 to 200		13	8	21
5. 200 to 250		7	2	9
6. 250 to 300		7		7
7. 300 to 350		10	1	11
8. 350 to 400		6		6
9. More than 400	2	32		34
Total	10	280	121	411

The ground waters of highest salinity occur in two areas. One of these areas extends along the trough of the Valley from north of Moffat in range 10, township 44, south to the east side of range 11 in township 38. In this area the highest salinity occurs in the vicinity of San Luis Lake, although the water of that lake was not highly saline during the period of this investigation. The other and smaller area of high salinity lies south and west of the Rio Grande in range 9, township 37, and in ranges 9 and 10, township 36. In the northern area high salinity is found in the deeper waters as well as in the subsoil waters, while in the southern area high salinity is confined to the shallow or subsoil waters.

In addition to determining the total concentration of the dissolved salts in the ground waters of the San Luis Valley, the present investigation also includes a number of detailed analyses in order to ascertain the character of the dissolved salts. Prior to the present investigation it had been known that in some of the ground waters the preponderant constituents were sodium and carbonate or bicarbonate, while in other ground waters the dominant basic constituents were calcium and magnesium. The analytical data includes on pages 198 to 219 the detailed analyses of water samples from 151 locations in the Valley, including one sample from a small saline lake (30–40–12). In respect to samples from 11 of these locations, the analyses were not sufficiently detailed to afford information as to all of the more important constituents.

The results of the more complete detailed analyses show that regardless of concentration there are at least two types of ground water that differ from each other in important particulars. The differences between representative samples of waters of the two types are shown in table 2. The first two samples listed in the table are similar in concentration and in composition to the surface waters that enter the Valley from the surrounding hills. The first of these two samples is from a deep well located on the west side of the Valley on the delta of the Rio Grande. The other sample is from the east side of the Valley on the delta of Trinchera Creek. In these two samples the dominant basic constituents are calcium and magnesium, and while the dominant acidic constituent is bicarbonate, there are present also appreciable proportions of sulphate and chloride.

TABLE 2.—*Typical ground waters of the San Luis Valley, Colo., showing the ratio of each constituent to the sum of the constituents of each group, i. e. cations and anions.*

[illegible]	Conductance [illegible]	Percentage of each Constituent					
		Calcium (Ca)	Magnesium (Mg)	Sodium [illegible] K)	Bicarbonate [illegible]	Sulphate [illegible]	Chloride [illegible] NO_3)
[illegible]	[illegible]	62	18	[illegible]	70	[illegible]	[illegible]
[illegible]	21.7	71	18	11	[illegible]	[illegible]	[illegible]
[illegible]	182	1	[illegible]	97	97	[illegible]	2.5
10 37 10 (14M10L1)	29.5	[illegible]	[illegible]	[illegible]	92	6	[illegible]

The second pair of samples shown in the table represent the conditions found in the "soft" ground waters of the central part of the Valley. One of these is from a deep well located in the trough of the Valley about 5 miles northwest of San Luis Lake. It has been selected as representing the rather saline yellowish or brownish water that is found under an extensive area of the central section of the Valley. Its dissolved salt is composed almost wholly of sodium carbonate or bicarbonate. Many of the waters of this type in this area contain flammable gas of the hydrocarbon type. The other sample of "soft" water is from a well located at Alamosa, south of the Rio Grande and west of the Valley trough. The ground waters represented by this sample are usually not colored, do not contain gas, and have low salinity like the inflowing surface water, but the proportions of calcium and magnesium are very low.

The inference is that the deeper waters circulating through the sediments of the central part of the Valley have been subject to base exchange reactions and possibly also to some reduction or decomposition of the sulphate constituent. The soft water from these wells has doubtless been an important factor contributing to the occurrence of extensive areas of "tight" or relatively impermeable soil that exist in the lower sections of the Valley.

The significant and characteristic difference between the two types of water shown in table 2 lies in the sodium percentage. In the first pair of samples this percentage is low, less than 30, while in the second pair it is high, more than 80. A summary of the conditions found in the San Luis Valley in respect to the sodium percentage of the ground waters is shown in table 3. The locations from which the more complete detailed analyses were made are classified into 10 groups. It will be seen that in the case of the 100 deep wells there are 44 with low sodium percentages, i. e., less than 30, while there are 30 wells with sodium percentages above 80. The waters from the shallow wells and from the springs tend to fall into these groups rather than into the intermediate position. It seems probable that in the case of the shallow wells the high sodium percentages are the result of local contamination by waste water from adjacent deep wells rather than of the natural accumulation of such water in the subsoil from irrigation with surface water.

TABLE 3.—*Ground waters of the San Luis Valley, Colo., classified as to sodium percentages*

[illegible]	Springs	Shallow wells	Deep wells	Total locations
[illegible]		1	[illegible]	1
[illegible]		3	[illegible]	[illegible]
[illegible]	3	6	19	28
[illegible]	2	2	12	16
[illegible]		1	8	[illegible]
[illegible]	1	1	1	3
[illegible]	[illegible]	3	[illegible]	[illegible]
70 to 80		4	3	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	2	7	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	100	139

One notable characteristic of the ground waters of the San Luis Valley is the frequent occurrence of fluoride and the occasional occurrence of boron. Not all of the analyses included the determination of these elements and the quantities found were listed in the present report when the fluoride was not less than 1.0 p. p. m. or when the boron was not less than 0.55 p. p. m. Of the samples from 151 stations in the Valley, fluoride of 1.0 p. p. m. or more was reported for 44 and among these were 14 samples containing more than 0.55 p. p. m. of boron.

For the San Luis Valley as a whole, it may be said that the ground waters around the margins are of low salinity with low sodium percentages, being similar in character to the inflowing surface waters. In the lower sections of the Valley there are two areas in which the shallow or subsoil waters are generally rather saline. Toward the middle of the Valley the deeper water is generally "soft", i. e., has a high sodium percentage and in the area north of the eastern edge of the Rio Grande delta the deeper waters are both soft and rather saline.

PART IV
SECTION 4.—THE MIDDLE RIO GRANDE VALLEY

Surface Waters

The Middle Rio Grande Valley as here delimited includes that section of the drainage basin extending from the Colorado State line south some 230 miles to the San Marcial gaging station. In the present investigation, water samples have been obtained from 24 stations on 15 tributaries that join the main stream in this section. On the east side from Costilla Creek on the north to Galisteo Creek there are 10 small streams, while on the west side there are 5 streams, 2 of which, the Chama and the Puerco, are relatively large. Samples were obtained also from 5 stations on 4 tributary streams south of San Marcial, 2 from the west side of the river and 2 on the east side. Of these 4 streams probably only 1, the Alamosa, that discharges into Elephant Butte reservoir makes any surface contribution to the main stream.

The waters contributed from the east by the streams north of Galisteo Creek are all of low salinity with conductances ranging from 4.8 up to 72, with only one station above 50. The sodium percentages are also low, none exceeding 30. For Galisteo Creek, which is dry much of the time, there is only one sample. This sample, with conductance of 212, probably does not represent the normal flood discharge of the stream.

The Rio Chama, an important tributary from the west, has been sampled at six stations. Its waters are also of low salinity with conductances less than 80 and with sodium percentages less than 30. Conditions are different in Jemez Creek. This stream drains a region in which soft rocks are exposed and in which there are salt springs. Some of the flood waters from torrential rains are not highly saline but the low water discharge is strongly so, with conductances ranging well above 400. The Rio Puerco and Rio Salado that join the main stream above the San Acacia gaging station are also rather saline. In both of them the waters of the latter part of a flood may have conductances below 100, but the low-stage discharge and the first flood waters are likely to range up to 400 or more. The dissolved salts carried by these last-named streams—the Jemez, Puerco, and Salado—consist largely of sulphates of calcium, sodium and magnesium. The sodium percentages seldom range much above 50. Of the four streams south of San Marcial, the samples from only one, Tularosa Creek, had conductances ranging above 100. No detailed analyses were made on samples from these streams.

The main stream of the Rio Grande, on leaving the San Luis Valley in Colorado, enters a canyon section at 7,425 feet above sea level and emerges from that section 120 miles south, above Cochiti, at 5,230 feet elevation. From Cochiti to San Marcial, a distance of approximately 165 miles, its gradient is lower, about 4.5 feet per mile, and it meanders through a flood plain sometimes 4 or 5 miles wide. In this section the river bed is only slightly lower than the flood plain and along much of its course it has been necessary to confine the river channel by levees on one or both sides. On the land side of these levees the borrow pits have been interconnected to make intercepting drainage canals which are known as riverside drains. The irrigated land along this section of the stream lies chiefly on the flood plain and is watered by canals that head at successive diversion points. The sedimentary material of the valley fill is saturated with water and the surface of this saturated zone is seldom more than 5 or 6 feet below the ground surface and is often closer. In order to keep the subsoil water from rising so high as to cause crop injury a system of open drains has been constructed through the irrigated land. These are known as interior drains. These interior drains discharge into the river or into the Riverside drains, which in turn discharge into the river, and these waters are again diverted for irrigation farther down the stream.

In the present investigation water samples were taken from the main stream of the Rio Grande at two stations above Cochiti and at 11 points from Cochiti to San Marcial, inclusive. The conductances of these samples are reported on pages 100 to 105 of the analytical data and the results of the detailed analyses are given on pages 226 to 229. These analytical data show that there is a general increase in salinity in the down stream direction. This increase in salt concentration may be due in part to the contributions made by the Jemez, Puerco, and Salado and in part to the dissipation of water by plant use and by evaporation taking place on the irrigated lands. The analytical and discharge data do not afford an adequate basis for estimating what quantities of water and of dissolved salts enter the Middle Valley by way of the Rio Grande at Cochiti and what part enters from its tributaries between Cochiti and San Marcial, or of estimating the quantities that pass out at San Marcial. This subject will be considered in a later part of the present report.

In addition to the samples taken from stations on the main stream of the Rio Grande, the irrigation supply of

the Middle Valley was sampled at 22 stations on 15 of the more important canals. Eight of the canals supply land west of the river and seven are on the east side. On six of these canals samples were taken at two or more stations to learn whether the water was appreciably different toward the lower end of the canal than near its head. The findings of this part of the investigation are that the canal water is much the same as the river water and that there is no appreciable difference between samples taken near the head of the canal and those taken lower down on the same canal. The conductances tend to range higher in the canals that take water from lower down stream than in those that take off at the upper end of the valley. There is one that is exceptional. It is Jaral lateral no. 1 (index no. 17–5–2). The water sampled from this canal showed conductances consistently higher than that of adjacent canals. For 17 consecutive samples taken from July to December 1936 the conductances ranged from 129 to 173. The water in this canal comes not from the river but from the lower Belen Riverside drain, which in turn carries the water of the Sausal interior drain.

At one of these canal stations, at the head of Arenal main canal near Albuquerque, it was deemed advisable to take samples more frequently than once a week to learn if there were differences from day to day in the salinity of the water. The samples taken at this station (p. 109 of the analytical data) are assumed to represent the water in the Rio Grande as it passes Albuquerque. The record of these 95 consecutive samples shows that in general the differences from day to day were slight. There were times however, notably early in August and again late in September, when the daily differences were large.

While the data so far available are not sufficient to justify an attempt to estimate the quantities of dissolved salts that annually move past any given point in the Middle Valley, they do appear to justify an estimate as to the concentration or conductance of the water passing certain of the control stations. The control stations selected for consideration are the following:

(1) Cochiti, the uppermost diversion point for the Middle Valley;

(2) Isleta, which is at the lower end of the Albuquerque division;

(3) San Acacia, which is at the lower end of the Belch division; and

(4) San Marcial, which is at the lower end of the entire Middle Valley.

In the upper division, between Cochiti and Isleta, two tributaries, Galisteo Creek and Jemez Creek, enter the Valley. In the next division, between Isleta and San Acacia, the Rio Puerco and Rio Salado enter. Finally all the Valley drainage is returned to the main stream above San Marcial. In arriving at a single mean value for the conductance of the water passing each station during the period of the present investigation the conductance data are taken not only for the samples collected at the station but also the samples taken from the irrigation canals that head at the station. Thus the mean for the Cochiti station is derived from samples taken at the river station and at two points on the Sili Canal and two on the Cochiti Canal. The Isleta mean includes results from the Belen and Peralta canals, and the San Acacia mean includes the data from the Socorro canal. The mean for San Marcial, not weighted for discharge, is based on 63 consecutive samples taken during the year ending October 1, 1936. The mean conductance values for the four stations are shown in table 4. It is evident from this table that there is a progressive increase in salinity at the successive stations in the down-stream direction. It is evident also that the percentages of sodium and of chloride increase progressively in the same direction.

TABLE 4.—*The mean conductance values and the sodium and chloride percentages of water passing successive control stations on the Rio Grande through the Middle Valley in New Mexico during 1936*

Station	Number of samples	Mean conductance ($K \times 10^5$ at 25° C.)	Percent	
			Sodium (Na)	Chloride (Cl)
Cochiti	83	37.9	27	7
Isleta	85	[illegible]	34	11
San Acacia	[illegible]	89.0	[illegible]	17
San Marcial	[illegible]	100.7		

It has been noted above that where the elevation of the river channel is nearly as high as that of the land on either side, levees have been built to confine the stream, and that on the land side of these levees open channels, known as riverside drains, have been made. The water collected in these riverside drains is returned to the river at favorable points. This water is evidently derived in part from lateral percolation from the river channel and in part from water percolating directly from the irrigated land or discharged by the interior drains.

In the present investigation water samples were taken from a number of stations on these riverside drains. The number of such samples and the mean conductance values for the three main divisions of the valley are shown in table 5. It will be seen that these conductance values are somewhat higher for each division than the corresponding values reported for the river and irrigation-canal samples in table 4. The increased concentration for each division ranges from 26 to 39 percent. This is probably not a valid comparison, however, because there is wide variation in the salinity of the samples from the different drains. In some of them the water is very similar to that of the river, while in others the salinity is much higher. In the Belen division, for example, the lower Belen River

side drain is much more saline than the river. Salinity is relatively high also in the San Antonio and Limitar riverside drains in the lower division. It seems probable that in these cases the water in the riverside drains is contaminated from the land side either by percolating subsoil water or by the discharge of interior drains.

TABLE 5.—*The mean conductance values of water samples from riverside drains in the Middle Rio Grande Valley, N. Mex., 1936*

Division	Number of samples	Mean conductance ($K \times 10^5$ at 25° C.)
Cochiti to Isleta	407	52.7
Isleta to San Acacia	333	71.1
San Acacia to San Marcial	119	110.7

The conditions of salinity found in the waters of the interior drains are extremely variable. Some of these drains evidently are cut through permeable soil areas so that they collect large quantities of water of low salinity, while others serve areas where the subsoil water is more saline. In the report of analytical data, pages 112 to 145, conductance data are reported from 76 stations on 37 named interior drains, and detailed analyses of samples from 40 of these stations are reported on pages 230 to 245. Some of these named drains are branches of others and there are in some cases several successive stations on the same drain.

The more important of the interior drains are listed in table 6. This table shows also the approximate length of each drain, including branch drains, above the lowest sampling station, the approximate discharge, the mean conductance, and the character of the dissolved salts as expressed by the percentage of sodium and of chloride.

An examination of the data of table 6 shows that the water of these interior drains varies greatly in salinity. This variation is less pronounced among the drains of the upper division than among those of the middle and lower divisions. In the lower division the mean conductance of the water in one drain is 58.9, while that of another is 303. There are similar differences among the drains in respect to the sodium and chloride percentages of the water.

In order to show the comparative salinity found in the irrigation water, in the Riverside drains, and in the interior drains, their mean conductance data are assembled in table 7. It should be noted that while for the irrigation water the means are based on data from samples taken at the three diversion points and in canals heading at these points, the data for the Riverside drains include all samples taken from these drains. In both cases the means have not been weighted by the discharge. The means for the interior drains include only samples from one station on each drain; the one nearest the outlet, and these means have been weighted by the discharge. The data of table 7 show that while with the irrigation water and the Riverside drains there is a progressive increase in salinity in the downstream direction, this is not true with the interior drains. Reference to the data of table 6 shows that in the lower (Socorro) division the water of two drains is of remarkably low conductance. In fact, in these drains, Lopez C and Lopez B, the mean conductances are lower than the mean conductance of the irrigation water for that division. The explanation for this phenomenon is not apparent from the data at hand.

TABLE 6.—*Characteristics of interior drains of the Middle Rio Grande Valley, N. Mex., 1936*

Name	Station index no.	Approximate length above station, miles	Approximate discharge, c. f. s.	Mean conductance ($K \times 10^5$ at 25° C.)	Mean percent	
					Sodium	Chloride
Upper division:						
[illegible]	31-15-5	3.0	7.0	[illegible]	27.5	4.7
Bernalillo	14-12-3	4.5	2.0	108.7	66	[illegible]
Corrales	34-12-3	1.1	2.0	81.0	31	[illegible]
[illegible]	13-10-2	13.0	35.0	93.3	[illegible]	12
San Jose	7- 9-3	2.7	3.0	79.7	25	[illegible]
Barr	1- 8-2	4.0	10.0	117.3	43	[illegible]
Isleta	23- 8-2	24.0	51.0	80.7	36	[illegible]
Middle division.						
Otero	14- 7-2	3.0	4.0	99.2	[illegible]	15
Los Lunas	27- 7-2	2.2	4.0	116.4	40	12
San Fernandez	3- 6-2	1.2	2.0	65.8	[illegible]	11
Tome	4- 5-2	20.3	32.0	153.0	45	16
Las Chaves	8- 5-2	13.0	15.0	202	60	[illegible]
Bosque	25- 4-1	[illegible]	[illegible]	195	52	23
Las Nutrias	36- 3-1	6.0	12.0	96.7	48	15
Bernardo	10- 2-1	3.5	12.0	204.3	[illegible]	28
[illegible]						
San Acacia	11- 1-1	4.0	5.0	303	59	51
Chamizal	24- 1-1	1.5	3.0	116.3	29	43
Polvadera	1- 2-1	3.0	2.0	193.0	45	42
Lopez C	20- 3-1	5.5	15.0	76.6	[illegible]	13
Lopez B	31- 3-1	1.5	3.0	58.9	32	16
Lopez A	[illegible]	5.4	[illegible]	[illegible]	71	49
Elmendorf	20- 5-1	2.0	5.0	114	47	20

TABLE 7.—*Comparison of the mean conductance of the irrigation water with that of the Riverside drains and the interior drains in the Middle Rio Grande Valley, N. Mex., 1936*

Division	Mean conductance of samples		
	Irrigation	Riverside drains	Interior drains
Cochiti and Albuquerque	37.9	52.7	[illegible]
Belen	53.2	71.1	163.0
Socorro	[illegible]	110.7	155.0

Ground Waters

The area involved in the present investigation lies in the flood plain adjacent to the Rio Grande, and extends from the Angostura diversion dam at the north line of township 13 north, to a point just above San Marcial gaging station in township 6 south, a distance of approximately 120 miles. The flood plain, which includes all of the irrigated land, ranges up to 5 miles in width, but is constricted to a mile or less at several places. Two of these constrictions, the one at Isleta

and the one at San Acacia, separate the valley into three natural subdivisions. Each of these divisions is known by the name of its principal town. They are in succession from north to south, Albuquerque, Belen, and Socorro.

In order to obtain information as to the elevation of the surface of the saturated zone of the subsoil in the flood plain a large number of observation wells have been established. For the most part these wells are in lines that cross the valley in an east-west direction. They are approximately a mile apart. The investigation of the conditions of salinity in the subsoil waters is based upon samples taken from certain of these wells. In general all of the wells in a selected line were sampled three times during the latter part of the summer of 1936. The conductance data for these samples are reported on pages 146 to 167 of the analytical data. Samples from one or more wells in each line, thought to be representative, were taken for detailed analyses. These results are reported on pages 246 to 255 of the analytical data.

The tables of conductance data include also the elevation of the water surface in each well at the date of sampling. These elevation data, when compared with the best obtainable data as to the elevation of the water surface in the river, in line with the wells, show that in general the subsoil water is lower than the water in the river. It is not apparent that there is any consistent relationship between the elevation of the water surface in the wells and the salinity of the water. It is to be inferred that the wells of low salinity are surrounded by permeable subsoil through which water moves freely in the direction of the valley gradient. Conversely, it is probable that the wells of high salinity are located in areas where the subsoil water does not move freely and where the topographic conditions have long favored the evaporation of water from the soil with the consequent deposition of the residual dissolved salts.

In addition to these samples of the subsoil water, a number of samples were obtained from representative wells that penetrate to the deeper underground water such as is used locally for domestic and industrial purposes. These samples were analyzed in detail with results reported on pages 256 to 261 of the analytical data.

In discussing the data obtained from these analyses of the ground waters they will be grouped according to the divisions of the valley. It was to be expected, and it was found to be a fact, that the salinity of the water obtained from these observation wells varied between wide limits. With a few exceptions the successive samples from any one well were similar but adjacent wells were often very different. The ranges in mean conductance found in the observation wells of the three divisions are as follows:

[illegible]	From 49 to 1,790
[illegible]	From [illegible] to 5,450
[illegible]	From [illegible] to 7,290

It will be noted that in respect to the maximum salinity found, the lowest value was in the upper division and the highest value was in the lower division. This was not true in respect to the lowest salinity. The lowest mean value was found in the Socorro division, along with the highest.

A summary of the conditions found in each of the three divisions of the Middle Valley in respect to the salinity of the ground waters is presented in table 8. The first entries in this table relate to wells sampled for conductance only. The mean conductances reported for each division of the valley show that in general there is an increase in salinity from the upper to the lower end of the valley. The second group of entries in the table relate to the samples selected for detailed analysis from among the larger number of wells sampled for conductance only. It is evident that fairly representative wells were selected because the mean conductance values for these wells, about one-fourth of the total number sampled, are very close to the mean values for the larger number. The data as to the percent sodium and percent chloride show trends in the same direction as the conductance values.

From the data reported for the deep wells it is evident first, that in general the deeper waters are somewhat less saline than the shallow or subsoil waters; yet the mean values for conductance are somewhat higher for the deep wells of each division than those reported for the inflowing surface waters (table 4). The values for the percentages of sodium and of chloride, while only slightly different from those for the shallow wells, are appreciably higher than those reported for the inflowing surface water.

TABLE 8.—[illegible]

	[illegible]querque	[illegible]	[illegible]
[illegible]			
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	357
[illegible]	[illegible]	37	[illegible]
Mean conductance ($K \times 10^4$ at 25° C.)	[illegible]	[illegible]	319
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	13	20	[illegible]
[illegible]			
[illegible]	11	[illegible]	12
[illegible]	73.5	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

Another comparison that may be made is that between the salinity of the water from the shallow wells and that found in the interior drains. It is to be inferred that both the wells and the drains are supplied from the same zone of subsoil water. The fact is that the mean conductance values for the wells as shown in

table 8 are nearly twice as high as the corresponding mean values for the drains as shown in table 7.

This difference is probably due largely to the conditions of subsoil and topography where some of the wells of high salinity are located. These conditions may be such as to favor the evaporation of water and at the same time to retard or even to inhibit the lateral movement of the concentrated residual water. The subsoil water that reaches the drains is more likely to do so by moving through the more permeable subsoil, while the water that saturates the less permeable subsoil may be dissipated chiefly by evaporation and thus become more concentrated with residual dissolved salts. It is to be expected, therefore, that the subsoil water that finds its way to the drains represents the water contained in the more permeable subsoil, while the wells being located at random in respect to subsoil conditions, probably give a better representation of salinity conditions in the whole mass of subsoil water.

There is one characteristic of the subsoil waters of the Middle Rio Grande Valley that calls for comment. That is the fluoride content. Samples of this water from 92 stations were analyzed for this constituent. It was reported absent for only 6 of these stations. For 39 stations its concentration was less than 1 p. p. m., while in 40 stations it ranged from 1 to 4 p. p. m., and for 7 stations it was 4 p. p. m. or more. It should be understood, of course, that these subsoil waters are probably not much used for drinking purposes. Some of the samples in which the higher fluoride concentrations were found were too saline to be acceptable for domestic use. However, there appears to be little correlation between the fluoride content and total salinity in this group of samples. The analyses of the samples from the deeper wells included the determination of fluoride for only a few stations and for these the concentrations were mostly low.

PART IV
SECTION 5.—THE ELEPHANT BUTTE PROJECT

Surface Waters

The area here designated as the Elephant Butte project includes that section of the Rio Grande Drainage Basin lying between the San Marcial gaging station on the north and the Fort Quitman gaging station on the south. Within this area the irrigated lands of the Elephant Butte project lie on the flood plains adjacent to the stream and are almost continuous from Percha Dam, located at the north line of township 17 south, in New Mexico, to the intersection of the river with the eastern boundary of El Paso County, Tex. On the south side of the river below El Paso there is an area of irrigated land in Mexico that is not included in the Elephant Butte project. There is also an area of irrigated land in Hudspeth County, Tex., east of El Paso County and above the Fort Quitman gaging station that is not included in the Elephant Butte project or in the present investigation.

The Rio Grande enters the Elephant Butte area at the northeast corner of sec. 25, T. 7 S., R. 2 W., N. Mex. P. M., where the zero of the gage at the San Marcial station is 4,455.38 feet above sea level and the water surface of the stream is 6 to 8 feet higher. It leaves the area at the Fort Quitman, Tex., gaging station, where the zero of the gage is 3,454.06 feet above sea level and the water is usually 2 feet or less above that elevation. The Fort Quitman station is approximately 180 miles south and 84 miles east of the San Marcial station, a distance by river of approximately 240 miles.

There are several small ephemeral streams that enter the Rio Grande from the west between San Marcial and Las Cruces, N. Mex. None of importance enters from the east or from either side south of Las Cruces. Local torrential rains falling in this narrow section of the basin cause temporary floods and add something to the water supply. But the major portion of the water used in the Elephant Butte area enters by way of the main stream at San Marcial.

Elephant Butte Dam, located about 38 miles below San Marcial, creates a reservoir that when full backs the water up nearly to the gaging station. Water is released from this reservoir during the irrigation season to supply the irrigated land of the Elephant Butte project and certain lands in Mexico, below El Paso.

The irrigated lands of the Elephant Butte project fall into three divisions, separated by natural constrictions of the valley. The first or uppermost of these is the Rincon division. This is irrigated by water diverted from the river at Percha Dam, located near the north line of township 17 south, about 20 miles below Elephant Butte Dam. The division extends to the south line of township 19 south. The flood plain throughout this division is narrow, seldom more than a mile wide.

The next division, the Mesilla Valley, begins at Leasburg Dam, located in sec. 10, T. 21 S., R. 1 W., and extends southward across the State line into Texas, ending at another constriction of the valley just above the El Paso (Courchesne) gaging station in sec. 9, T. 27 S., R. 4 E., a distance of nearly 60 miles. The flood plain of the Valley in this division ranges up to 4 miles in width. Its irrigation water is diverted not only from Leasburg Dam but also from Mesilla Dam, located in sec. 13, T. 24 S., R. 1 E.

The lower or El Paso Valley division occupies the flood plain on the north side of the river from the city of El Paso to a point about a mile west of the line between El Paso and Hudspeth Counties where higher land approaches close to the river channel, here the international boundary. This division is about 33 miles long and ranges up to 4 miles in width. Its irrigation water is diverted from the river at three points: (1) at International Dam just west of El Paso city limits; (2) at Riverside heading, 2 miles south of the town of Isleta; and (3) at Tornillo canal heading about a mile south of the town of Fabens.

In the Elephant Butte project there is not a definite system of riverside drains such as are found in the Middle Valley. There is, however, an extensive system of open drains in each of the divisions of the project. The water collected by these drains in each division is returned to the river above the point of diversion for the next division farther down stream.

In connection with the present investigation, the waters of the Rio Grande have been sampled at 8 successive stations below San Marcial, beginning at the outlet of Elephant Butte Dam and ending at Fort Quitman gaging station. The waters collected by the drains of the project have been sampled at 29 stations. The conductance data in respect to these samples are reported on pages 168 to 175 of the analytical data. Certain detailed analyses of samples from some of these stations are reported on pages 262 to 265.

The subject of the quality of the irrigation and drainage water of this project had been under investigation

for several years before the present investigation was begun. The results of these earlier investigations have been incorporated in the present report and will be considered in the discussion of it.

At the moment only scant reference will be made to the data based on samples collected from the successive stations along the main stream. These data will be discussed in a later chapter of the report. It may be noted here that the conductance results on page 169 of the analytical data show that during the late summer of 1936, the salinity of the water increased at each successive diversion point from a mean of 87.9 at Percha Dam to a mean of 398 at Fort Quitman. These values should not be taken as the best expression of conditions at these stations but they do illustrate the fact that the salinity of the river water increases as it passes through the project. The trend of the volume of discharge is shown by this same table to be in the opposite direction. The mean discharge at Percha Dam for the sampling dates was 1,739 cubic feet per second while the means for the sampling dates at Fort Quitman was only 88 cubic feet per second. These values also should not be taken as the best available. A more complete summary of the discharge and salinity conditions along this section of the stream will be given in a later chapter.

In respect to the drains of the project, data as to volume of discharge and salinity are available for relatively long periods. As early as 1918 the Bureau of Reclamation began to take water samples from some of them and to determine the total dissolved solids by evaporating a filtered aliquot and weighing the dry residue. This program of sampling was continued through 1936. The rates of discharge and total dissolved solids for the drain as reported by the Bureau of Reclamation are given on pages 270 to 285 of the analytical data.

In order to supplement this inquiry with information as to the composition of the dissolved salts, additional samples have been taken for detailed analyses. During the period from January 1929 to July 1930, five sets of samples were taken in this inquiry. Again from April 1933 to January 1934, four sets of samples were taken. Finally, a single set of samples was taken in August 1936. The results of the detailed analyses of these 10 consecutive samples are shown on pages 286 to 295 of the analytical data.

In addition to the samples taken in 1936 for detailed analysis, consecutive samples were taken from each drain during the late summer of 1936 for conductance determination. The results are given on pages 168 to 175 of the analytical data. The means for the discharge, the total dissolved solids and the conductance obtained by these three different investigations show fairly good agreement in respect to each drain where comparisons are possible. This appears to indicate that in volume and in concentration the discharge of a drain has been fairly constant, at least during recent years. This makes it possible to show in tabular form some of the characteristics of each of the drains in the project. The data presented in the following tables are from the findings on the samples taken for detailed analysis from 1929 to 1936. It should be understood that these data are not to be taken as the truest and most accurate that could be derived from all the information available. They do, however, show approximately what the conditions of discharge and salinity have been.

In the Rincon division there are four drains as shown in table 9. Each of these drains discharges into the river. Their combined length is 41.7 miles. Their mean discharge is 1.1 cfs. per mile of drain with a combined annual discharge of 36,400 acre-feet of water. In mean salinity they range from 1.05 to 1.35 tons per acre-foot, and they discharge annually about 48,000 tons of dissolved salts. Because of the relatively large volume of water carried by the river through this division of the project the effect of this return flow is not appreciable. In fact the salinity of the drainage water is very little higher than that of the river itself.

For the Mesilla Valley division of the project there are 12 drains listed in table 10. Not all of these discharge directly into the river. The Leasburg and Mesilla drains discharge into the Del Rio drain and the Nemexas and West drains discharge into Montoya. The net totals shown in the table refer to the system that returns water to the river. The combined length of the drains of this division is 210 miles, or slightly more because some of the stations are above the outlets. The volume of discharge per mile of drain ranges from 0.7 to 1.7 cfs. with a mean of 1.15 or slightly more than the mean for the Rincon division. The combined annual discharge for the drains of the division is 205,000 acre-feet of water carrying 383,000 tons of dissolved solids.

TABLE 9.—*Drains of the Rincon division, Elephant Butte project, New Mexico; length of drain; discharge of water and of dissolved solids*

Name	Length (miles)	Discharge		Dissolved salts		
		Cubic feet per second per mile	Acre-feet per year	Tons per acre-foot	Tons per year	Year-tons per mile
Garfield	12.4	1.2	10,800	1.33	14,400	1,160
Hatch	10.8	1.3	10,600	1.33	14,100	1,300
Angostura	4.1	.7	2,000	1.05	2,100	510
Rincon	14.4	1.2	13,000	1.35	17,500	1,210
Total [illegible]			[illegible]		48,100	

By way of comparison it may be noted that the mean annual discharge at Leasburg Dam, at the head of the

TABLE 10.—*Drains of the Mesilla Valley division, Elephant Butte project, New Mexico and Texas; length of drain; discharge of water and of dissolved solids*

[illegible]	[illegible] (miles)	[illegible]				
		[illegible]		[illegible]		
		[illegible]	[illegible]	[illegible] foot	[illegible] per [illegible]	[illegible]
[illegible]	[illegible]	[illegible]	3,600	[illegible]	[illegible]	1,100
[illegible]	[illegible]	[illegible]	8,300	1.01	8,400	[illegible]
[illegible]	[illegible]	1.2	6,200	1.15	7,100	1,000
[illegible]	[illegible]	[illegible]	8,300	1.30	10,800	[illegible]
[illegible]	73.1	1.5	77,700	1.32	102,600	1,400
[illegible]	5.3	1.0	3,700	2.13	7,900	1,500
[illegible]	[illegible]	1.7	27,400	1.13	[illegible]	1,400
[illegible]	22.9	1.0	15,900	4.06	[illegible]	2,800
[illegible]	7.7	1.0	5,300	2.34	12,400	1,600
[illegible]	[illegible]	1.2	17,200	2.50	[illegible]	2,100
[illegible]	39.0	1.3	[illegible]	1.61	60,400	1,500
[illegible]	67.6	1.2	[illegible]	[illegible]	152,100	[illegible]
[illegible]	[illegible]		[illegible]		383,000	

Mesilla Valley division, is approximately 745,000 acre-feet of water carrying approximately 650,000 tons of dissolved solids, while the corresponding values at El Paso (Courchesne) in the lower end of the division are 523,000 acre-feet and 638,000 tons. Between the upper and the lower gaging station there is an annual loss of 220,000 acre-feet of water and possibly 10,000 tons of dissolved salts. If the actual diversion of water to the irrigated lands of the division were restricted to the quantity currently consumed, namely 220,000 acre-feet, this water would carry to the land annually 190,000 tons of dissolved salts none of which would be returned to the river. It seems inescapable that the annual addition of 190,000 tons of dissolved salts to the irrigated soils of the division would, in time, impair their productivity. There may be a question as to whether it is necessary to divert 200,000 acre-feet of water in addition to the 220,000 acre-feet consumed in order to carry away the residual salt and maintain a salt balance within the division. But it seems obvious that there must be diverted enough water in excess of the quantity consumed to carry away the residual salt.

Conditions in the El Paso Valley division are less simple than in the Mesilla Valley division. The latter includes all the irrigated land contiguous to and served by the irrigation and drainage systems. In the El Paso Valley division on the other hand a substantial quantity of water, possibly 100,000 acre-feet annually, is diverted across the international boundary and there are no data as to the quantity or salinity of the drainage return from that water. Then, too, the water to irrigate San Elizario Island (the island district) is diverted above Fabens. Finally, there is an area of irrigated land in Hudspeth County between the Elephant Butte project and Fort Quitman gaging station, to which water is diverted below Fabens but for which no data are available as to drainage return. Consequently the best that can be done in respect to the El Paso Valley division is report the findings as to the drains located in that division and compare these findings with the known condition at the Courchesne station above the division and at the Fort Quitman station below it, leaving out of account the conditions on the irrigated lands in Mexico and in Hudspeth County, Tex.

There are six drains that discharge into the river. The volume of discharge per mile of drain ranges from 0.5 to 1.8 cubic feet per second. The combined length of the drains as shown in table 11 is 193.4 miles and the combined annual discharge is 133,000 acre-feet, carrying 494,000 tons of dissolved salts. The mean annual discharge at Courchesne, at the head of the Valley, is approximately 523,000 acre-feet carrying 638,000 tons of salt, while at Fort Quitman the mean annual discharge is approximately 172,000 acre-feet, carrying 473,000 tons of salt. It appears from this comparison that while the annual discharge of the drains from this division is some 50,000 acre-feet less than that of the river at Fort Quitman, their annual salt burden is some 21,000 tons larger.

TABLE 11.—*Drains of the El Paso Valley division, Elephant Butte project, Texas; length of drain; discharge of water and of [illegible]*

[illegible]	[illegible] (miles)	[illegible]				
		[illegible]		[illegible]		
		Cubic [illegible]	[illegible] year	Tons [illegible] acre-foot	[illegible]	[illegible] tons [illegible] mile
[illegible]						
[illegible]	23.6	1.3	22,900	2.11	48,300	[illegible]
[illegible]	36.8	1.2	32,900	2.68	88,200	[illegible]
[illegible]	55.3	1.2	46,400	3.10	[illegible]	[illegible]
[illegible]	23.4	.9	15,400	3.83	59,000	2,520
[illegible]	8.6	.8	5,000	1.62	8,100	[illegible]
[illegible]	29.1	.5	10,600	3.21	[illegible]	1,170
[illegible]	1.9	1.8	2,500	2.64	6,600	3,470
[illegible]	118.3		79,900		[illegible]	2,800
[illegible]						
[illegible]	[illegible]	[illegible]	8,500	[illegible]	[illegible]	1,980
Island	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4,180
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Tornillo	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Net total	[illegible]		[illegible]		[illegible]	
Division total	[illegible]		[illegible]		[illegible]	[illegible]

It should be emphasized that these values for discharge and salt burden should be taken as only approximations of the truth. They are presented here rather to indicate the trend of relationships than to give definite estimates. Furthermore the comparisons between the total drainage discharge and the discharge of the river at Fort Quitman are not valid because some of the drains join the river above Fabens, so that some of the water

and of the salt that they discharge is diverted, just below Fabens, into the Tornillo canal, and these totals thus include some water and salt that is counted twice.

It now remains to consider the characteristics of the dissolved salts removed from the irrigated land of the Elephant Butte project in comparison with those of the water of the Rio Grande as it is diverted to the land for irrigation and as it is influenced by the return of the drainage water. In order to facilitate comparisons between the conditions in the several drains and in the river above and below the drains it is advantageous to show, in addition to the concentration of the dissolved solids, the proportions of each of the major salt constituents. There are six of these constituents—three cations, calcium, magnesium, and sodium, and three anions, bicarbonate, sulphate, and chloride. In computing the percentage composition of the salt constituents the sum of the cations, as milligram equivalents, is divided into the value for each cation (multiplied by 100) and the sum of the anions is similarly divided into each anion value. These percentage values are then directly comparable with each other regardless of the concentration of the solution.

The conditions reported for each of the drains listed in the following three tables are based on the findings reported in the tables of detailed analyses for these drains on pages 286 to 295 of the analytical data. The mean values reported have not been weighted for different discharge values. The mean annual discharges of water and of dissolved solids for each drain have similarly been computed from the arithmetical, not the weighted mean values. The percentage composition values reported for the gaging stations on the Rio Grande above and below each division are based on weighted means.

The conditions found in the drains of the Rincon division are reported in table 12. It will be noted that the values representing concentrations, i. e., conductance and total dissolved solids are higher in each drain than in the river water either above or below the division. In respect to the several salt constituents the calcium is higher in three of the drains than in the river water; the magnesium is lower in all of the drains. The values for sodium reported for the drains range above and below those of the river. The same is true for bicarbonate. The sulphate values for the drains are consistently lower while the chloride values are consistently higher than in the river.

The comparable data for the river at Elephant Butte outlet, above the Rincon division and for Leasburg Dam below it, show that while the volume of the drainage is relatively small and its salinity is not relatively high, there is an appreciable increase in salinity between the two river stations. This increase may be due in part to salts brought into the river by creeks or washes that enter it along this section. There is no other information as to the quantity or quality of such contributed waters.

The Mesilla Valley division is much larger in area than the Rincon division and has more drains. The conditions found in these drains are shown in table 13, together with comparable data for the river stations above and below the division.

It is evident from the data of table 13 that the aggregate discharge of the drains constitutes a large part of what passes the Courchesne station, namely 40 percent of the water and 60 percent of the dissolved solids. The mean concentration of the drainage water of the division is 1.87 tons per acre-foot and the effect of this contribution on the river has been to increase its concentration from 0.87 ton per acre-foot at Leasburg to 1.22 tons per acre-foot at Courchesne.

The data as to percentage composition show that there are pronounced differences among the drains not only in concentration but also in the composition of their dissolved solids. The range in concentration is from 1.01 tons per acre-foot for Leasburg drain up to 4.06 tons per acre-foot for east drain. There are certain trends of change in composition that occur with the increase in concentration, namely, as the concentration goes up the percentages of sodium and of chloride also rise but the percentages of the other four constituents tend to decline.

The drains of the El Paso Valley division fall into two groups, those that discharge into the river above Fabens and those that contribute to the Tornillo drain and return to the river at the lower end of the project. The data for each of these drains in respect to discharge, concentration, and percentage composition are given in table 14. In general the drain waters of the El Paso Valley division are more concentrated than those of the Mesilla Valley and Rincon divisions but they differ among themselves both in concentration and in composition. The drains above Fabens range in concentration from 1.62 tons per acre-foot in Quadrilla drain to 3.83 tons per acre-foot in River drain. The mean concentration of the net total drainage discharge from this area is 3.15 tons per acre-foot.

The drains of the Island and Tornillo districts all discharge through Tornillo drain. The contributing drains range in mean concentration from 2.50 tons per acre-foot for Fabens drain up to 8.25 tons per acre-foot for Border drain with a mean concentration for the entire discharge of 4.59 tons per acre-foot. In percentage composition these drain waters are also somewhat variable but they are all high in sodium and particularly in chloride and low in bicarbonate.

In respect to the quantities of water and of dissolved solids discharged by the drains and those carried by the

TABLE 12.—*The drains of the Rincon division, Elephant Butte project, New Mexico; characteristics of their discharge as compared with that of the river above and below the division, 1930–36*

	[illegible]		[illegible]		Constituent percentages					
	Water (acre-feet)	Total dissolved solids (tons)	Conductance K [illegible] at 25° C.	Total dissolved solids [illegible] per acre-foot)	Ca	Mg	Na	HCO_3	SO_4	Cl
[illegible]	[illegible]	[illegible]	[illegible]	0.81	[illegible]	[illegible]	44	32	51	[illegible]
[illegible]	[illegible]	14,400	[illegible]	1.33	43	13	44	[illegible]	40	[illegible]
[illegible]	[illegible]	[illegible]	137	1.33	49	13	38	31.5	44	24.5
Angostura	[illegible]	[illegible]	109	1.05	48	13	39	36	41	[illegible]
[illegible]	[illegible]	[illegible]	142	1.35	41	12	[illegible]	26.5	45.5	[illegible]
Total	[illegible]	18,100		1.32						
[illegible]	[illegible]	[illegible]	[illegible]	.87	[illegible]	14	[illegible]	[illegible]	[illegible]	20

TABLE 13.—*The drains of the Mesilla Valley division, Elephant Butte project, New Mexico and Texas; characteristics of their discharge as compared with that of the river above and below the division, 1930–36*

	[illegible]		[illegible]		Constituent percentages					
	Water [illegible]	Total [illegible] solids (tons)	[illegible] K [illegible] at 25° C.	Total dissolved solids [illegible] per acre-foot)	Ca	Mg	Na	HCO_3	SO_4	Cl
[illegible]	744,982	647,406	91	[illegible]	41	14	45	31	49	20
[illegible]	[illegible]	5,100	159	1.43	[illegible]	12	52	26	35.5	38.5
[illegible]	8,300	8,400	108	1.01	44.5	13.5	42	37	[illegible]	22
[illegible]	[illegible]	7,100	120	1.15	44	15	41	[illegible]	42	[illegible]
[illegible]	8,300	10,860	137	1.30	[illegible]	13.5	45.5	34	43	23
[illegible]	[illegible]	102,600	133	1.26	[illegible]	12	46	32	40	28
[illegible]	[illegible]	[illegible]	230	2.13	[illegible]	12	55	23	36	41
[illegible]	27,400	31,000	121	1.13	41	12	47	34	40	[illegible]
[illegible]	15,900	[illegible]	442	4.06	17	10	[illegible]	15	[illegible]	53
[illegible]	5,300	12,400	264	2.34	25	13	62	[illegible]	32	45
Nemexas	17,200	43,000	280	2.50	26	10	64	21	[illegible]	[illegible]
[illegible]	[illegible]	60,400	[illegible]	[illegible]	[illegible]	12	59	27	41	32
[illegible]	65,300	152,100	261	2.33	25	10	[illegible]	20	36	44
Net totals	205,000	383,000		1.87						
[illegible]	522,758	637,968	127	1.22	35	12	53	26	43	31

river at the Courchesne and Fort Quitman stations, comparisons are not valid because of the facts that some of the water passing Courchesne is diverted to lands in Mexico and that the irrigated lands along the river in Hudspeth County, Tex., may use some water from the river and may contribute some salt to it above Fort Quitman. However, it is to be noted that the volume of the drainage discharge from the two districts of the El Paso Valley division equals 78 percent of the discharge at Fort Quitman while the salt tonnage from the drains is 5 percent greater than that carried by the river past Fort Quitman.

The conditions in respect to the surface waters of the Elephant Butte project may be summarized briefly. The river brings into the area annually from Elephant Butte Reservoir about 766,000 acre-feet of water carrying about 620,000 tons of dissolved solids. It takes away from the area, past Fort Quitman, about 172,000 acre-feet of water carrying about 473,000 tons of dissolved solids. Between these two stations on the river the irrigation and drainage of the contiguous agricultural lands result not only in changing the concentration of the dissolved solids of the stream waters, but they change also and appreciably the composition of those dissolved solids. The change of concentration is upward at each successive station along the stream and this is accompanied by higher concentrations in the drain waters and in the subsoil waters as sampled from observation wells. The changes in composition are in the direction of higher percentages of sodium and of chloride with lower percentages of the other four major constituents.

Ground Water

While the salinity conditions of the ground waters of this area as represented by the water collected by the open drains has been under investigation for several years, there appear to be no data from observation wells prior to 1936. Beginning in August of that year 77 wells were established and the water surface elevations were recorded and samples were taken for conductance determinations until the end of November. Of these 77 wells, 4 were located in the Rincon division, 18 in the Mesilla Valley division, and 55 in the El Paso Valley division.

From some of these wells as many as nine successive samples were taken for conductance measurements but from many others only three samplse were taken.

TABLE 14.—*The drains of the El Paso Valley division, Elephant Butte project, Texas; characteristics of their discharge as compared with that of the river above and below the division, 1930–36*

	Mean annual discharge		Mean concentrations		Constituent percentages					
	Water (acre-feet)	Total dissolved solids (tons)	Conductance $K \times 10^5$ at 25° C.	Total dissolved solids (tons per acre-foot)	Ca	Mg	Na	HCO_3	SO_4	Cl
El Paso (Courchesne)	522,758	637,968	127	1.22	35	12	53	26	43	31
Above Fabens:										
Playa	22,900	48,300	234	2.11	31	13	56	20	29	51
Franklin	32,900	88,200	300	2.68	29	13	58	17	28	55
Middle	46,400	143,800	353	3.10	30	10	60	14	29	57
River	15,400	59,000	419	3.83	32	10	58	13	27	60
Quadrilla	5,000	8,100	180	1.62	28	11	61	23	42	35
Mesa	10,600	34,000	351	3.21	27	10	63	16	36	48
Fabens, intercepting	2,500	6,600	289	2.64	36	13	51	17	34	49
Net total	79,900	251,500	....	3.15	....	....	....	....	....	....
Island and Tornillo:										
Fabens	8,500	21,200	299	2.50	36	12	52	16	30	54
Island	12,500	77,600	720	6.21	31	8	61	7	17	76
Border	4,700	38,800	945	8.25	27	7	66	5	19	76
Alamo	9,400	33,800	409	3.60	30	11	59	12	30	58
Tornillo	52,900	242,800	517	4.59	32	9	59	9	22	69
Net total	52,900	242,800	....	4.59	....	....	....	....	....	....
Division total	132,800	494,300	....	3.72	....	....	....	....	....	....
Fort Quitman	172,373	473,129	296	2.75	26	11	63	12	29	59

With very few exceptions, the conductance values of these successive samples are in close agreement so that the mean values for each well are believed to be good. During the same period of time that the wells were under observation, samples were taken from the drains that serve the same areas. In general the conductance values of these successive samples of drain water are also in good agreement, so that it seems warranted to consider together the mean salinity of the drains and the mean salinity of the water from wells as representing the ground waters of each area.

In the uppermost or Rincon division of the project there are four drains and four wells. Two of these wells are contiguous to the uppermost or Garfield drain. The ground waters of this division appear to be of low salinity. The mean conductance values for the drains range from 130 to 152, with a mean for the four of 145. The corresponding values for the wells range from 190 to 218, with a mean of 200. The mean conductance of the irrigation water used in this division was about 90.

Of the 18 wells in the Mesilla Valley division, 2 at the lower end of the division are so situated as not to be comparable with the contiguous drain. The mean conductance values of the remaining 16 may be so compared and this is done in table 15. It will be noted that in the seven comparisons the mean values for the wells are higher than in the contiguous drains in five cases and lower in two. The unweighted means are 206 for the drains and 237 for the wells. The evidence from these observation wells, confirmed by that of the drains, is that in the Mesilla Valley division the subsoil water is not very saline except in two areas, one along the east side of the valley above Anthony and the other along the middle of the valley, west of the river, below Anthony. Of the two wells not listed in the table, one is located just north of Montoya drain syphon, and the other just north of the gaging station of Montoya drain. The first has a mean conductance of 342 and the other is very saline with a mean conductance of 2,574.

TABLE 15.—*Mean conductance values of the wells of the Mesilla Valley division and of contiguous drains*

Drain	Length (miles)	Mean conductance	Number of contiguous wells	Range of conductance	Mean conductance
Del Rio	73.1	143	2	153–206	180
Picacho	7.2	130	1	....	228
La Mesa	21.8	125	1	....	146
Chamberino	5.3	221	1	....	201
East	22.9	374	7	154–446	301
West Drain	39	184	2	125–255	190
Nemexas	20.2	267	2	400–425	412
Mean		206	...		237

The El Paso Valley division, lying along the river southeast of El Paso, comprises three districts. Midway down the valley the river leaves its old channel, the international boundary, and crosses to the northeastern side near the town of Fabens, thence to turn south again and reenter its old channel at a point about 2 miles southeast of the town of Tornillo. The uppermost district (above Fabens) lies between the river and the higher, unirrigated land to the northeast. The island district is the area, opposite Fabens, between the present river channel and its old channel. The Tornillo district lies below Fabens, between the river and the mesa. Of the 55 wells in the El Paso Valley division, 11 are located in the district above Fabens,

7 are in the island district, and 37 are in the Tornillo district.

[illegible] 16.—*[illegible] Valley division and of contiguous drains*

[illegible]	[illegible]	[illegible] duct-[illegible]	Contiguous wells		
			Num-[illegible]	Range of [illegible]	[illegible] conduct-[illegible]
[illegible]					
[illegible]	[illegible]	[illegible]	[illegible]	235-1196	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	163-1023	[illegible]
[illegible]	23.4	[illegible]	1	[illegible]	724
[illegible]		448	11		705
[illegible]	33.7	[illegible]		325-2583	854
Tornillo district.					
[illegible]	20.6	[illegible]	[illegible]	243-1301	503
[illegible]			20	[illegible]	528
[illegible]	[illegible]	497	[illegible]		570

A summary of the conditions of ground-water salinity as found in the El Paso Valley division is shown in table 16. In the district above Fabens the mean conductance of 11 wells is 705, while that of the 3 drains that serve the district is, for the same period, 448. In the island district the mean of 7 wells is 854, while that of the 3 drains is 559. In the Tornillo district the Tornillo drain, that serves the area between the Tornillo canal and the river, carries the discharge of the 3 drains of the island district as well as the water it collects in the Tornillo district. In the area between the Tornillo canal and the mesa served by the Alamo drain there are 17 wells with a mean conductance of 503, while the mean conductance of the Alamo drain for the same period is 395. For the combined island and Tornillo districts served by the Tornillo drain, there are 44 wells. The mean conductance of these 44 wells is 570, while that of the Tornillo drain is 497.

The following is a summary of salinity conditions found in the ground waters of the three major divisions of the Elephant Butte project in the summer of 1936

[illegible]	[illegible]	[illegible]
[illegible]	4 drains, 445	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]		
[illegible]	[illegible]	11 wells, 705.
[illegible]	3 drains, 497	44 wells, 570.

It is obvious that these data are not adequate to serve as a basis for a convincing picture of the ground water conditions of the Elephant Butte project. The observation wells are too few in number and they give samples only from the upper surface of what may be assumed to be a deep body of water contained in the sediments of the valley fill. The data show that there are wide differences in salinity between wells that are not far apart. Had the wells been located in different positions from those selected for the present inquiry, different mean values might have been obtained. Furthermore, in the absence of information as to the conditions of salinity in the deeper waters of the valley sediments, there exists the possibility that there is little relationship between the subsoil water sampled from the observation wells and that collected by the drains. It seems probable, in fact, that much of the subsoil water that finds its way into the drains represents deeper subsoil water entering them from below as a result of hydrostatic conditions in the system consequent on percolation from irrigation canals. It is not necessarily to be inferred that the water appearing in these open drains comes chiefly by way of lateral flow along the surface of the saturated zone of the subsoil. Waters percolating downward from irrigation canals or through the readily permeable areas of irrigated lands may displace the subsoil water locally and the consequent hydrostatic readjustments may take place through deep permeable aquifers to the drains rather than through the lateral movement of the surface horizon of the subsoil water.

The findings of other investigations [1] show that there is in fact very little lateral translocation of water in the surface of the saturated zone of the subsoil, even when the elevations of that water surface show appreciable gradients. Closely adjacent wells that have been under observation for 10 years or more, and in which the seasonal vertical movement may be 3 feet or more, continue to show wide differences in salinity.

The presentation here of data concerning the salinity of water in observation wells and in contiguous open drains should not be taken as warranting the inference that there is thought to take place normally a lateral movement to the drains of the water represented by the wells. The purpose of presenting the data in summary form is to show what conditions of salinity were found to exist in the area.

Samples were taken for detailed analysis from 23 of the observation wells in the Elephant Butte project. The results are given on pages 266 to 269 of the analytical data. Summarized briefly, these analyses show that in respect to the percentages of sodium and chloride there is a progressive increase in the downstream direction. The mean percentages for the wells of the three major divisions are as follows:

Division	Number of wells	[illegible]	
		Sodium	Chloride
[illegible]	[illegible]	46.5	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	67.3	[illegible]

[1] [illegible]

PART IV

SECTION 6.—THE WATERS OF THE RIO GRANDE ABOVE FORT QUITMAN, TEX.

The Gaging Stations

In the preceding chapters of this report consideration has been given to conditions of salinity found in the surface and ground waters of the three major divisions of the Rio Grande Drainage Basin above Fort Quitman, Tex. It now remains to discuss the conditions found at the several control or gaging stations along the main stream. There are nine such stations for which data are available in respect to the volume of discharge and the quality of the water. Two of these are in Colorado. The uppermost station, near Del Norte, is located above the points of diversion for San Luis Valley. The next, the State Line station, is located near Lobatos and below the tributary streams and drains of the San Luis Valley.

Below the Lobatos station the river enters a canyon section in northern New Mexico, in which it receives the flow of several tributaries, chief of which is Rio Chama, from the west. Toward the lower end of this canyon section is the third gaging station at Otowi Bridge. After leaving the canyon section, the river emerges into a section of lower gradient with alluvial lands on either side. This is the Middle Valley which extends to the San Marcial gaging station, located just above Elephant Butte Reservoir. In the Middle Valley some tributaries join the main stream; chiefly Jemez Creek and Rio Puerco and Rio Salado. The drains serving the irrigated lands of the Middle Valley also discharge into the main stream above San Marcial.

Elephant Butte Reservoir collects the flow of the main stream passing San Marcial and receives also some water from small local streams. Water from the reservoir is released chiefly during the irrigation season from April to September each year. There is a sampling station at the outlet of the reservoir. Leasburg Dam, the next sampling station is located below the Rincon division of Elephant Butte project and above the Mesilla Valley division. Courchesne station is below the Mesilla Valley division and above the points of diversion to lands in Mexico and to the El Paso Valley division of the Elephant Butte project. There are no important tributaries reaching the river in the Mesilla Valley division but drains that serve the irrigated land discharge into the river above the Courchesne station.

About midway down the El Paso Valley division is located the Tornillo-Fabens station. Topographic conditions in the El Paso Valley are such that most of the drains serving the irrigated land above Fabens discharge into the river above that station and at that station water is diverted from the river into Tornillo canal to serve lands below Fabens. The Fort Quitman station, the last one of this series, is located about 35 miles below the lower end of Elephant Butte project. In the section between the Courchesne and Fort Quitman stations no important tributaries join the main stream, but the drains that serve the contiguous irrigated land discharge into the stream above Fort Quitman.

Sampling and Analyses

The conditions at each of these gaging stations, in respect to the volume of discharge and quality of water, vary from day to day and from year to year. At most of them, observations as to the volume of discharge have been made and recorded for many years past. It is only recently that systematic observations have been made concerning the quality of the water by collecting and analyzing samples. Such data as are available in respect to the samples collected at these stations are reported in the analytical data, pages 10 to 54. For the Del Norte station, data on quality are available only for 1936. For the Lobatos and Otowi Bridge stations the record covers the 3 years, 1934 to 1936.

For the San Marcial station the record is much longer. During the period from May 1905 to April 1907, samples were taken about twice a week at this station and their partial analyses, together with the volume of discharge, are reported in Water Supply Paper 274, published by the United States Geological Survey. These data have not been incorporated in the present report. During the period from April 1920 to June 1932 the river was again sampled at this station and the total dissolved solids were determined. These data, together with the record of the discharge at the time of sampling, are reported in the analytical data, pages 13 and 14. From June 1932 to December 1936 samples were taken approximately once a week and the detailed analyses of these are also reported in the analytical data.

At the outlet of Elephant Butte Reservoir occasional samples were taken from 1920 to 1930 for the determination of total dissolved solids. In 1931 and 1932 samples were taken at this station about once a month for detailed analyses. Since June 1933 samples have

been taken more frequently. For purposes of comparison, samples have been taken also from the surface of the reservoir above the dam.

The record of quality for the Leasburg Dam station includes the total dissolved solids for occasional samples taken from 1920 to 1930 and the detailed analyses of weekly samples or of monthly composites of weekly samples taken since 1931.

At the Courchesne station, near El Paso, Tex., a series of samples was taken and analyzed, like those at San Marcial, during 1905 to 1907, also reported in Water Supply Paper No. 274, but not here incorporated. From June 1918 to January 1930 occasional samples were taken for the determination of total dissolved solids and these results, together with results of the detailed analyses of weekly samples or of monthly composites are reported in the analytical data.

The record for the Fabens-Tornillo station includes the data as to the total dissolved solids found in samples taken during the period from 1918 to 1930 and the detailed analyses of weekly samples or monthly composites since January 1930. Finally the record for Fort Quitman includes the total dissolved solids on occasional samples or of monthly composites since January 1930.

The summarized findings, here presented, as to salinity conditions along the main stream are based on 1 year's record at Del Norte, 3 years' at Lobatos and Otowi Bridge, 4 years' record at San Marcial, and 6 years' records at the five stations from Elephant Butte outlet to Fort Quitman. No attempt is here made to interpret the findings of the earlier reports of analyses for the stations having older records.

Before proceeding to discuss the findings based on the data here presented, it seems proper to consider the validity and the significance of the data. It seems unnecessary to labor the point that on such a stream as the Rio Grande the conditions of discharge and of the quality of the water passing a gaging station are extremely variable. Appreciable changes may occur within an hour and great changes may occur from day to day. Such changes are less pronounced at some seasons of the year than at others but they are continual and characteristic.

The customary procedure of sampling for investigating the quality of the water is to take a sample from time to time, such as once a day, once a week, or once a month, using reasonable care that the sample represents the discharge at the time. The volume of discharge at the time of sampling is estimated or measured and recorded on the sample label, along with the date and the name of the collector. These individual samples may be analyzed separately or they may be assembled into composites representing some period of time, such as a month. In making up such composite samples for analysis, the procedure here followed is to take from each individual sample a quantity proportional to the volume of discharge each sample represents.

In any event, whether the individual samples are analyzed separately or proportionately composited before analysis, the results of an analysis are evaluated or weighted by the discharge values that each represents, when it is desired to estimate the quantities of dissolved solids or of any constituents passing the station during any period of time, such as a year. This procedure rests on the assumption that a sample taken at any given time truly represents the water passing the station during the time-period allocated to that sample. As a matter of fact, it is well known that at several of these gaging stations on the Rio Grande the changes that occur from day to day or even from hour to hour in volume of discharge and in quality of the water are such as to invalidate the assumption of uniformity during the time-period involved in the present sampling program. Fortunately, the resulting errors do not run in one direction and in time they tend to cancel each other. But it should be kept in mind in considering the quantitative data here presented as to the salt burden of the stream, that these computed values can be at best only approximations of the truth.

It is believed that the results reported for the individual analysis are valid and acceptable. Their validity may be and has been tested in a variety of ways. The sources of error mentioned above are inherent in the system of periodical sampling rather than in the methods of analysis. One of the ways of testing the validity of the analyses is to compare the results obtained from any sample or any group of samples in respect to similar or related characteristics of the water. For example, one of the more important characteristics of water is the quantity of dissolved solids it contains; in other words, its concentration. By the methods of analysis used in the present investigation we obtain three independent measurements of concentration:

(1) An aliquot of the sample, carefully filtered, is evaporated, the residue is dried and weighed. The result, computed as total dissolved solids (t. d. s.), is reported as tons per acre-foot of water.

(2) The specific electrical conductance of the sample is determined by measuring the electrical resistance of a known volume at known temperature. The result is reported as conductance $K \times 10^5$ at 25° C.

(3) Each of the six or eight more important constituents of the dissolved salts is separately measured and reported in terms of milligram equivalents per liter. The sum of these milligram equivalents is also a measure of concentration. It does not include all the dissolved material (e. g. silica) but is nevertheless an acceptable relative measure of concentration.

In the course of reporting water analyses these three criteria of concentration are compared as a means of guarding against errors. Long experience has shown that in a series of samples from any one source their

ratios to each other are remarkably constant. These ratios differ somewhat among themselves with samples from different sources having different compositions, as is to be expected.

Computing the Data

In the matter of weighting the results of invididual analyses in respect to the discharge volumes they represent, more than one procedure is possible. According to the sampling program followed in the present investigation, at least two methods of weighting analytical results have been used. The earlier method adopted and still in use in respect to certain of the stations is as follows: The individual samples received from a station are separately analyzed. All of the analyses for each month are then taken as being representative of the total discharge for that station for that month and the arithmetical mean for each characteristic or constituent is computed. Subsequently, when the discharge data for that station (in acre-feet per month) become available the mean values for the month's analyses are multiplied by that discharge. By the other method, the samples from each station for each month are made into a composite for one analysis. Each sample contributes to this composite a quantity that is proportional to the discharge (in cubic feet per second) that was reported with it. The data from this single analysis are subsequently multiplied by the reported discharge for that station in acre-feet per month.

Neither of these methods is wholly satisfactory or free from error. Neither takes adequately into account the differences in volume of discharge or of salinity that regularly occur at these river stations. Attention is here called to the obvious and admitted faults in the methods of computation used in the present report in order to avoid the implication that the findings here presented are regarded as definitive and the most accurate that could be obtained. They represent merely one interpretation of the detailed analytical data. Other and more refined methods of computation might yield results that would be nearer the truth.

The objective of the present discussion of the analytical data concerning the regimen of the Rio Grande is to show what the conditions are at each of the nine control or gaging stations described above. A summary will be given of the findings for each station for each year of record, together with a summary for each station for the whole period of record. Comparisons will then be made between pairs of stations as a means of showing the effects of conditions between them, and as showing the trend of changes that occur from the upper to the lower stations.

Because of the fact that only 1 year's record, 1936, is available for the uppermost station, near Del Norte, Colo., a summary of that year's record is shown in table 17, and for comparison data are given for the same year for the Lobatos station, located below the San Luis Valley. The table shows first the volume of water, in acre-feet, passing each station during the year as reported by the State Engineer of Colorado. The next entry reports the total dissolved solids, in tons, passing each station during the year as computed from the analysis of one composite sample from each station for each month. These composite samples were made up at the laboratory from four or five individual samples with each of which was reported the estimated discharge, in cubic feet per second, at the time of sampling. The determined concentration of total dissolved solids, as tons per acre-foot, was then multiplied by the discharge, in acre-feet, subsequently reported for each month, and the sum of these products is reported as the second entry in the table. The third entry is the mean concentration as tons per acre-foot, obtained by dividing the value for discharge, in acre-feet, into the value for tons of total dissolved solids.

The values given for conductance were obtained by multiplying the conductance determined for each individual sample by the discharge value reported with that sample, adding these products together for the whole year and dividing that sum by the sum of the individual discharge values. The method of obtaining the third concentration value, i. e., the sum of the milligram equivalents, will be described later.

The next seven entries in the table give the values for the tonnage of each of seven constituents of the dissolved solids. These values are obtained by the following method: The value for the discharge, in acre-feet, for each month is multiplied by the value reported, as milligram equivalents, for the constituent as obtained by the analysis of the composite sample for that month, and this product is then multiplied by a factor to convert it into tons. The sum of these tonnages for each month is reported as the tonnage for the year.

The mean composition for the station is then computed by dividing the value for the annual discharge, in acre-feet, into the value for the annual tonnage of each constituent and then dividing this quotient by the factor that was used for computing the tonnage of each constituent. The sum of the milligram equivalent values for the mean composition is then taken as the third measure of concentration referred to above.

The percentage composition reported by the last six entries in the table is obtained by dividing the value for the sum of the cations into the value for each cation and the value for the sum of the anions into the value for each anion. In computing the percentage composition when potassium is reported, its value is added to the value for sodium. Similarly, when the nitrate

ion is reported, its value is added to that for chloride before dividing by the sum of the anions.

TABLE 17.—*The Rio Grande above and below San Luis Valley, Colo.; discharge conditions at two control stations; data for* [illegible]

Item	Del Norte station	[illegible] (State line) station
[illegible]		
[illegible]	472,300	[illegible]
[illegible]	51,976	[illegible]
Concentrations:		
[illegible]	0.11	[illegible]
Conductance	8.46	26.51
[illegible]	[illegible]	5.71
Constituents (tons):		
[illegible]	7,203	[illegible]
[illegible]	2,074	2,698
[illegible]	4,408	8,039
[illegible]	13,715	[illegible]
[illegible]	9,731	18,268
[illegible]	2,818	3,881
[illegible]	197	[illegible]
[illegible]		
[illegible]	[illegible]	1.39
[illegible]	.27	.58
[illegible]	.30	.91
[illegible]	1.13	2.88
[illegible]	.70	1.54
[illegible]	.32	1.00
[illegible]	.12	[illegible]
[illegible]	T.	T.
Sum (anions)	[illegible]	2.83
[illegible]		
[illegible]	50	48
[illegible]	24	[illegible]
[illegible]	26	[illegible]
[illegible]	[illegible]	55
[illegible]	28	[illegible]
[illegible]	[illegible]	10

The Stream Above San Marcial

With this explanation of the methods used in computing the data shown in the following tables, the conditions found at the Del Norte and Lobatos stations for 1936 may be compared. It may be recalled that below the Del Norte station water is diverted from the Rio Grande to irrigate land in San Luis Valley. Drainage water from the irrigated land is returned to the river above the Lobatos station and several tributary streams also join the river above the latter station. The table shows that the total volume of water passing the Lobatos station was 191,350 acre-feet less than that passing the Del Norte station. The volume at Lobatos was approximately 60 percent of that at Del Norte. The total dissolved solids passing Lobatos was greater than the quantity passing Del Norte by 22,521 tons for the year, or 45 percent.

The changes occurring between Del Norte and Lobatos, i. e., the loss of water and the gain of dissolved solids, are reflected in the differences of concentration shown for the two stations. The concentration at Lobatos, as shown by the total dissolved solids and the sum of the milligram equivalents, is approximately 2.5 times that at Del Norte. As measured by conductance, the difference is greater; about 3.1 times that at Del Norte. The discrepancy between the conductance criterion and the other two is owing, in part at least, to the different methods used in computing these weighted mean concentration values.

The notable fact about the river as sampled at these two stations is that its water contains very little dissolved material in comparison with the water farther down the stream. Even though the concentration of the water at the Lobatos station is 2.5 to 3 times as high as at Del Norte, it is still not very saline.

The data for the percentage composition shown in the last six entries of table 17 show the nature of the changes in composition that occur between the two stations. These values show that the water passing the Lobatos station contains relatively less calcium, magnesium, and bicarbonate than the waters passing Del Norte, and relatively more sodium and sulphate. There is only a slight difference in respect to the chloride percentage.

The conditions at the Lobatos station for 1 year, 1936, were shown in table 17. The conditions at that station for the past 3 years, 1934–36, are summarized in table 18. This record shows that the annual volume of discharge varied widely, from 99,000 acre-feet in 1934 to 360,000 acre-feet in 1935. The range in the salt tonnage carried is not quite so great and, consequently, the concentration was higher in the year of low discharge. The character of the salts, as shown by the percentage composition, differed very little from year to year.

TABLE 18.—*Lobatos (State line) gaging station, Colorado, showing the quantities of water, of dissolved solids, and of each of the more important salt constituents passing the station during each calendar year, 1934 to 1936.*

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Discharge:				
Water (acre-feet)	98,910	360,340	280,950	246,733
Dissolved solids (tons)	[illegible]	[illegible]	74,495	66,553
Concentrations:				
[illegible]	0.364	0.217	[illegible]	[illegible]
[illegible]	37.4	26.4	[illegible]	27.9
[illegible]	8.69	5.26	[illegible]	5.84
Constituents (tons):				
[illegible]	5,214	12,164	10,601	9,326
[illegible]	[illegible]	3,168	2,698	2,377
[illegible]	[illegible]	9,991	8,039	7,562
Bicarbonate (HCO_3)	[illegible]	21,809	18,006	16,261
[illegible]	10,841	19,834	18,268	16,314
Chloride (Cl)	1,918	5,063	3,881	3,621
[illegible]		[illegible]	[illegible]	167
Composition (milligram equivalents):				
[illegible]	2.16	1.24	1.39	1.39
[illegible]	.77	.53	.58	.58
Na	1.50	[illegible]	.91	[illegible]
Sum (cations)	[illegible]	2.66	2.88	[illegible]
[illegible]	2.18	1.46	1.54	1.58
[illegible]	[illegible]	[illegible]	1.00	1.01
[illegible]	[illegible]	[illegible]	[illegible]	.30
[illegible]		[illegible]	T	
Sum (anions)	[illegible]	[illegible]	2.83	2.89
[illegible]				
[illegible]	[illegible]	[illegible]	48	47
[illegible]	17	[illegible]	20	20
Sodium	[illegible]	33	[illegible]	[illegible]
Bicarbonate	51	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	11	[illegible]	[illegible]

The next station down stream from Lobatos is at Otowi Bridge, near San Ildefonso, N. Mex. In the canyon section between these two stations the river receives contributions from both sides, the most important one being Rio Chama, from the west. There are no important diversions between the two stations. The record of the Otowi Bridge station (table 19), like that of the Lobatos station, shows that 1934 was a dry year. The differences at Otowi Bridge were less than at Lobatos and this is true also as regards the discharge for 1935 and 1936. At Otowi Bridge these 2 years were very similar.

Comparison of the 3-year means for Lobatos and Otowi Bridge shows that between the two stations the river gained annually 604,000 acre-feet of water and 226,000 tons of dissolved solids. From this it may be inferred that water contributed between the two stations had a concentration equivalent to 0.37 ton per acre-foot, or slightly higher than that of the water passing the Lobatos station.

The record for the San Marcial station, as shown in table 20, covers a 4-year period, including the dry year, 1934. Conditions at San Marcial are such that this record is not very satisfactory. The station is located below the junction of Rio Puerco and Rio Salado which drain the uplands west of the Rio Grande. This area is subject to local, torrential, summer rains which may cause brief floods in these streams. These flood waters are often highly saline, at least in the first part of a flood or in the first flood after a long dry season, and as they pass the San Marcial station they cause abrupt changes in the regimen of the stream at that point. Because of these abrupt changes, both in the volume and salinity of the water, it is suspected that the periodical samples taken at the San Marcial station may not afford a basis for dependable estimates of the salt burden of the stream at that point.

Between Otowi Bridge and San Marcial the Rio Grande passes through the Middle Rio Grande Valley with its extensive irrigated area. Jemez Creek, Rio Puerco, and Rio Salado join the river from the west, bringing in rather saline waters. The 3-year records for the two stations show that notwithstanding the tributary contributions, the annual volume of water passing San Marcial is 137,000 acre-feet less than passes Otowi Bridge. The annual salt burden of the stream at San Marcial is nearly 300,000 tons greater than at the upper station. From the data now available it is not practicable to estimate how much of this increased salt burden is derived from the tributary streams and how much comes from the drainage of the irrigated land contiguous to the main stream.

Comparison of the mean percentage composition of the salts passing Otowi Bridge and San Marcial shows that at the lower stations the proportions of calcium, magnesium, and bicarbonate are lower while the proportions of sodium, sulphate, and chloride are higher.

By way of a summary of conditions found at the three stations above Elephant Butte Reservoir for the 3-year period ending with 1936, the mean values for each sta-

TABLE 19.—*Otowi Bridge gaging station, New Mexico, showing the quantities of water, of total dissolved solids, and of each of the more important salt constituents passing the station during each calendar year, 1934–36*

Item	1934	1935	1936	Mean
Discharge:				
Water (acre-feet)	380, 430	1, 100, 740	1, 071, 520	[illegible]
Dissolved solids (tons)	151, 861	374, 751	351, 692	[illegible]
Concentrations:				
Tons per acre-foot	0. 40	0. 34	0. 33	0. 34
Conductance	39. 3	30. 4	30. 5	31. 8
Sum (milliequivalents)	9. 14	7[illegible]	7. 49	7. 76
Constituents (tons):				
Calcium (Ca)	23, 361	66, 119	63, 899	51, 126
Magnesium (Mg)	[illegible]	10, 319	12, 220	9, 343
Sodium (Na)	17, 122	33, 263	30, 188	[illegible]
Bicarbonate (HCO$_3$)	[illegible]	106, 022	94, 126	80, 908
Sulphate (SO$_4$)	36, 496	88, 360	89, 807	71, 554
Chloride (Cl)	7, 297	12, 868	15, 488	11, 884
Nitrate (NO$_3$)	-------	1, 376	[illegible]	1, 137
Composition (milligram equivalents):				
Ca	2. 26	2. 21	2. 19	2. 21
Mg	. 87	. 57	. 69	. 66
Na	1. 44	. 97	. 90	1. 01
Sum (cations)	4. [illegible]7	3. 7[illegible]	3. 78	3. 88
HCO$_3$	2. 70	2. 32	2. 12	2. 29
SO$_4$	1. 47	1. 23	1. 28	1. 29
Cl	. 40	. 24	. 30	. 29
NO$_3$	-------	. 01	. 01	. 01
Sum (anions)	4. 57	3. 80	3. 71	3. 88
Percentage:				
Calcium	[illegible]	59	58	[illegible]
Magnesium	19	15	18	17
Sodium	32	26	24	26
Bicarbonate	59	61	57	59
Sulphate	32	32	35	33
Chloride	9	7	8	8

TABLE 20.—*San Marcial gaging station, New Mexico, showing the quantities of water, of total dissolved solids, and of each of the more important salt constituents passing the station during each calendar year, 1933–36*

Item	1933	1934	1935	1936	Mean
Discharge:					
Water (acre-feet)	[illegible]	244, 399	1, 029, 500	867, 500	713, 800
Dissolved solids (tons)	746, 567	269, 211	851, 265	653, 332	[illegible]
Concentrations:					
Tons per acre-foot	[illegible]	1. 10	[illegible]	0. 75	0. 83
Conductance	117. 3	131. 1	104. 3	79. 4	97. 2
Sum (milliequivalents)	23. 60	24. 52	18. 35	17. 31	18. 63
Constituents (tons):					
Calcium (Ca)	92, 698	32, 366	113, 018	88, 692	78, 025
Magnesium (Mg)	20, 668	6, 490	23, 838	18, 243	16, 190
Sodium (Na)	117, 952	43, 881	119, 081	98, 176	[illegible]
Bicarbonate (HCO$_3$)	93, 697	34, 222	130, 189	106, 707	90, 373
Sulphate (SO$_4$)	304, 381	104, 180	306, 842	232, 748	214, 590
Chloride (Cl)	75, 148	28, 153	77, 997	65, 974	57, 375
Nitrate (NO$_3$)	-------	-------	2, 141	768	1, 456
Composition (milligram equivalents):					
Ca	[illegible]	4. 87	[illegible]	3. 76	[illegible]
Mg	1. 75	1. 61	1. 40	1. 27	1. 37
Na	5. 26	5. 74	3. 70	3. 62	3. 90
Sum (cations)	11. 77	12. 22	9. 14	8. 65	9. 29
HCO$_3$	3. 15	3. 38	3. 05	2. 98	3. 05
SO$_4$	6. 51	6. 53	4. 57	4. 11	4. 61
Cl	2. 17	2. 39	1. 57	1. 58	1. 66
NO$_3$	-------	-------	-------	. 01	. 02
Sum (anions)	11. 83	12. 30	9. 19	8. 66	9. 34
Percentage:					
Calcium	40	40	44	43	43
Magnesium	15	13	15	15	[illegible]
Sodium	[illegible]	[illegible]	41	42	42
Bicarbonate	27	27	[illegible]	34	33
Sulphate	55	53	50	48	49
Chloride	18	20	17	18	18

TABLE 21.—*The Rio Grande above Elephant Butte Reservoir in Colorado and New Mexico, discharge conditions at 3 control* [illegible]

Item	[illegible] (State [illegible]	[illegible]	[illegible]
[illegible]			
Water (acre-feet)	246,733	[illegible]	[illegible]
Dissolved solids (to[illegible]	[illegible]	292,768	591,264
[illegible]			
[illegible]	0.27	0.344	0.83
[illegible]	27.9	31.8	97.2
[illegible]	5.84	7.76	18.63
[illegible]			
[illegible]	9,326	51,126	88,025
[illegible]	2,377	9,343	16,190
[illegible]	7,562	26,857	87,046
[illegible]	16,261	80,908	90,373
[illegible]	16,314	71,554	214,590
[illegible]	3,621	11,881	57,375
[illegible]	167	[illegible]	[illegible]

tion as to discharge, concentration, and tonnage of each salt constituent are brought together in table 21. It may be noted that between Otowi Bridge and San Marcial the concentration of the water increases by 2.4 to 3 times. In respect to certain constituents the tonnage increase is much greater than that. For example, the chloride tonnage at Otowi Bridge is 3.3 times that at Lobatos, while at San Marcial it is nearly 5 times as high as at Otowi Bridge.

The Stream Below San Marcial

Elephant Butte Reservoir constitutes a definite break in the continuity of the regimen of the Rio Grande. It is a storage and equalizing reservoir in which water is held from year to year in varying quantities. Consequently, the data as to the annual volumes of discharge at stations above and below the reservoir are unrelated unless the volume of water in the reservoir is taken into account. It does not seem pertinent to the present inquiry to attempt to correlate the conditions found at stations immediately above and below the reservoir. Consequently the following discussion starts with the consideration of findings at the station just below Elephant Butte Dam and follows downstream to the station near Fort Quitman, Tex.

In the early stages of the inquiry here reported it was assumed that the water held in Elephant Butte Reservoir would be thoroughly mixed and of uniform composition. Consequently it was thought to be adequate to take a sample of the water at the outlet once a month or even less frequently. This assumption proved to be unwarranted. It was found, as a matter of fact, that the quality of the water released from the reservoir may change suddenly and profoundly. Subsequent investigations have shown that the water of the reservoir is not ordinarily a homogeneous mixture. It is probably very seldom in that condition.

This is not an appropriate place to discuss in detail the phenomena that occur in the reservoir. The facts essential to such a discussion are not yet available. It is known, however, that at certain times turbid and saline flood waters enter the reservoir at its upper end and pass along the floor of the reservoir to emerge 2 or 3 days later through the outlet gates at the dam. It is known also that at other times flood waters, also turbid but of low salinity, enter the reservoir at its upper end and, after dropping their suspended silt, spread out over the surface of the reservoir, and, with comparatively little blending, reach the dam at the lower end. Such mixture as does occur in the reservoir appears to be dependent chiefly on differences of temperature between the surface and the deeper water. When the surface water gets colder than the deeper water, as during the autumn and winter, it sinks to the bottom, replacing the warmer water.

These conditions in the reservoir have been the cause of some anomalous findings in respect to the salt burden of the water released from it. The details of these findings are reported in the analytical data, pages 20 to 25, and are summarized by years in table 22. The data of this table show that, except for 1935, the quantity of water released from the reservoir each year has been less variable than the quantities passing the upriver stations. The drought of 1934 diminished the inflow for that year and caused a diminished outflow during the following year.

TABLE 22.—[illegible] *quantities of water, of dissolved solids, and of each of the more important salt constituents released from the reservoir during each calendar year, 1931–36*

Item	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]							
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Concentrations:							
[illegible]	0.82	0.79	[illegible]	[illegible]	[illegible]	[illegible]	0.81
[illegible]	82.6	83.4	73.0	88.8	[illegible]	[illegible]	87.0
[illegible]	19.15	[illegible]	16.37	18.71	[illegible]	17.87	[illegible]
[illegible]							
[illegible]	80,863	[illegible]	81,433	82,861	67,745	76,273	78,277
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sodium (Na)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Composition (milligram equivalents:							
[illegible]	3.96	[illegible]	[illegible]	[illegible]	3.91	3.75	[illegible]
[illegible]	1.18	[illegible]	1.30	[illegible]	1.47	1.28	1.34
[illegible]	4.37	4.11	3.29	4.12	[illegible]	3.88	[illegible]
Sum (cations)	9.51	[illegible]	[illegible]	[illegible]	[illegible]	8.91	9.13
[illegible]	3.17	[illegible]	[illegible]	[illegible]	[illegible]	2.66	2.97
[illegible]	4.85	4.83	[illegible]	[illegible]	5.51	4.76	4.69
Cl	1.62	1.46	1.29	1.56	1.81	1.54	1.53
NO_3					.01		
[illegible]	9.64	[illegible]	8.17	9.42	10.18	[illegible]	[illegible]
[illegible]							
[illegible]	[illegible]	[illegible]	[illegible]	11	39	42	[illegible]
[illegible]	12		16		15	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	10	11	16	[illegible]	11
[illegible]	33		11	[illegible]	28	30	[illegible]
[illegible]						53	[illegible]
[illegible]			16		18	17	17

The data as to mean annual concentration show variations from year to year that are not closely correlated with the discharge values or with each other. There

are inconsistencies also in the data for the annual tonnages of the several constituents of the dissolved solids and consequently in values for composition. These inconsistencies are believed to be due in part at least to inadequacies in the sampling program. They may be due in part also to phenomena of decomposition that occurred in some of the samples between the time they were collected and the time when they were analyzed. Such decomposition is known to occur in samples containing silt, rich in organic matter.

Notwithstanding the admitted anomalies and discrepancies in these data, they may be accepted, with some reservations, as reflecting conditions at the outlet of Elephant Butte Reservoir and they may serve also as a basis of comparison with conditions found at the gaging stations farther down the stream, as summarized in the following tables.

The data of table 23, summarizing the conditions found at Leasburg Dam, seem to require less in the way of explanation and apology than has been given for the data for the Elephant Butte station. The data for the two stations should be much alike because conditions along the stream between them are not such as to have much influence for change. No important tributaries join the stream in this section and the area of contiguous irrigated land is small. Here, as at Elephant Butte, the annual volume of discharge is relatively constant and the annual mean concentration of the water ranges between narrow limits. There are some anomalies in the table, as for example the low value for the tonnage of sodium in 1933 as compared with the values for other years. The value for chloride in 1932 seems high as does also that for bicarbonate in 1933. No explanation is offered for these apparent discrepancies. They may be due in part to errors of sampling or of analysis or it may be that things were that way.

The summarized data for the 6-year period for the two stations show that there has been about 20,000 acre-feet less water passing Leasburg annually than was released from the reservoir, and that this water carried annually about 27,000 tons more dissolved solids. Its concentration was in consequence slightly higher. The differences in composition of the salt were slight but indicate some increase in the proportion of chloride at the expense of the sulphate and bicarbonate constituents.

The conditions at the Courchesne gaging station near El Paso, Tex., are summarized in table 24. Between Leasburg Dam and this station the river serves a large area of irrigated land but receives no tributaries of consequence. It appears that this irrigated land acts in some measure as an equalizing reservoir in respect to the monthly discharges throughout the year. At this station also the mean annual concentration of the water ranges between rather narrow limits. A fact

TABLE 23.—*Leasburg Dam, N. Mex., showing the quantities of water, of total dissolved solids, and of each of the more important salt constituents passing the dam during each calendar year, 1931–36*

Item	1931	1932	1933	1934	1935	1936	Mean
Discharge:							
Water (acre-feet)	[illegible]	[illegible]	[illegible]	768,230	[illegible]	693,260	[illegible]
Dissolved solids (tons)	[illegible]	679,283	[illegible]	700,381	614,411	596,114	[illegible]
Concentrations:							
Tons per acre-foot	0.87	0.83	[illegible]	0.91	[illegible]	0.86	[illegible]
Conductance	88.8	92.2	80.0	[illegible]	102.9	91.5	[illegible]
Sum (milliequivalents)	20.50	20.97	17.73	20.17	21.61	19.23	[illegible]
Constituents (tons):							
Calcium (Ca)	82,718	88,785	83,205	86,115	73,732	76,306	[illegible]
Magnesium (Mg)	16,121	20,305	19,840	18,064	17,139	15,488	[illegible]
Sodium and potassium (Na+K)	111,142	126,036	95,015	106,338	94,317	91,116	[illegible]
Bicarbonate (HCO$_3$)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sulphate (SO$_4$)	240,618	[illegible]	[illegible]	267,787	234,825	220,720	[illegible]
Chloride (Cl)	70,552	97,857	65,873	70,002	65,522	64,545	[illegible]
Nitrate (NO$_3$)					1,103	1,475	[illegible]
Composition (milligram equivalents):							
Ca	4.12	4.01	3.71	4.12	4.29	4.05	[illegible]
Mg	1.32	1.51	1.46	1.42	1.67	1.35	1.45
Na	4.81	[illegible]	3.67	4.43	4.77	4.20	4.46
Sum (cations)	10.25	10.47	8.84	[illegible]	10.73	[illegible]	9.95
HCO$_3$	3.28	3.17	3.27	2.97	3.04	2.82	3.10
SO$_4$	4.99	4.84	3.96	5.34	[illegible]	4.88	4.91
Cl	1.98	2.49	1.66	1.89	2.15	1.93	2.01
Sum (anions)	10.25	10.50	[illegible]	10.20	10.88	[illegible]	10.02
Percentage:							
Calcium	40	39	42	41	40	42	41
Magnesium	13	14	16	14	16	14	14
Sodium	47	47	42	45	44	44	45
HCO$_3$	32	30	37	30	28	29	31
SO$_4$	49	46	44	51	52	51	49
Cl	19	24	19	19	20	20	20

TABLE 24.—*El Paso (Courchesne) gaging station, Texas showing the quantities of water of total dissolved solids, and of each of the more important salt constituents passing the station during each calendar year, 1931–36*

Item	1931	1932	1933	1934	1935	1936	Mean
Discharge:							
Water (acre-feet)	518,000	567,240	[illegible]	508,480	259,910	473,740	522,758
Dissolved solids (tons)	671,350	681,824	701,233	643,292	569,788	560,323	637,968
Concentrations:							
Tons per acre-foot	1.30	1.20	1.15	1.27	1.24	1.18	1.22
Conductance	131.1	132.0	111.7	137.8	122.8	129.9	127.2
Sum (milliequivalents)	30.82	31.92	26.21	28.25	27.91	27.28	28.71
Constituents (tons):							
Calcium (Ca)	75,198	[illegible]	74,480	68,818	60,919	63,782	[illegible]
Magnesium (Mg)	13,871	19,304	17,847	15,063	13,889	13,302	[illegible]
Sodium and potassium (Na+K)	137,448	155,431	129,932	116,530	103,051	103,389	124,297
Bicarbonate (HCO$_3$)	84,933	92,705	96,874	75,901	68,195	[illegible]	81,407
Sulphate (SO$_4$)	224,289	241,432	209,347	207,838	189,608	187,849	210,060
Chloride (Cl)	120,062	149,256	118,709	105,424	91,728	91,117	112,716
Nitrate (NO$_3$)					1,186	2,136	1,661
Composition (milligram equivalents):							
Ca	5.34	5.09	4.49	4.98	4.87	4.95	4.95
Mg	1.62	2.06	1.77	1.79	1.83	1.70	1.79
Na	8.48	8.76	6.82	7.33	7.16	6.98	7.59
Sum (cations)	15.44	15.91	13.08	14.10	13.86	13.63	14.33
HCO$_3$	3.95	3.94	3.83	3.60	3.57	3.55	3.74
SO$_4$	6.63	6.52	5.26	6.26	6.32	6.07	6.18
Cl	4.80	5.45	4.04	4.29	4.13	3.98	4.46
NO$_3$					0.03	0.05	
Sum (anions)	15.38	16.01	13.13	14.15	[illegible]	13.65	14.38
Percentage:							
Calcium	35	32	34	[illegible]	35	[illegible]	35
Magnesium	10	13	14	[illegible]	13	12	12
Sodium	55	[illegible]	52	[illegible]	[illegible]	51	[illegible]
Bicarbonate	26	25	29	25	25	26	26
Sulphate	43	41	40	44	[illegible]	44	43
Chloride	31	34	31	31	30	30	31

TABLE 25.—*Fabens-Tornillo gaging station, Texas, showing the quantities of water, of dissolved solids, and of each of the more important salt constituents passing the station during each* [illegible]

[illegible]	1931	1932	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]							
[illegible]	280,000	291,606	328,610	222,519	195,586	224,420	257,123
[illegible] solids (tons)	571,950	544,431	585,991	446,047	[illegible]	433,149	496,014
[illegible]							
[illegible]	2.04	1.87	1.78	[illegible]	[illegible]	1.93	1.93
[illegible]	[illegible]	198.7	185.1	[illegible]	[illegible]	[illegible]	212.0
[illegible]	49.66	46.04	40.90	[illegible]	[illegible]	44.17	45.51
[illegible]							
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	47,801
[illegible] (Mg)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11,396
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] (HCO_3)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] Cl)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]							
[illegible]							
[illegible]	7.96	6.76	[illegible]	[illegible]	[illegible]	6.90	7.05
[illegible]	[illegible]	2.78	[illegible]	[illegible]	2.75	2.75	2.69
[illegible]	[illegible]	13.48	[illegible]	[illegible]	[illegible]	12.40	13.01
[illegible]	[illegible]	[illegible]	20.37	22.91	22.96	22.05	22.75
[illegible]	[illegible]	[illegible]	4.41	4.38	[illegible]	4.10	4.38
[illegible]	[illegible]	[illegible]	7.32	[illegible]	8.29	8.26	8.12
Cl	[illegible]	[illegible]	8.80	10.36	10.52	9.72	[illegible]
[illegible]					.01	.04	
[illegible]	[illegible]	23.02	20.53	23.29	23.11	22.12	22.76
[illegible]							
[illegible]	32	29	31	31	31	32	31
[illegible]	[illegible]	12	13	12	12	12	[illegible]
[illegible]	[illegible]	[illegible]	56	57	[illegible]	56	[illegible]
[illegible]	19	19	21	19	18	19	19
[illegible]	33	[illegible]	36	37	[illegible]	37	[illegible]
[illegible]	[illegible]	45	43	[illegible]	[illegible]	41	[illegible]

TABLE 26.—*Fort Quitman gaging station, Texas showing the quantities of water, of total dissolved solids, and of each of the more important salt constituents passing the station during each calendar year, 1*[illegible]

[illegible]	1931	1932	1933	[illegible]	1935	[illegible]	[illegible]
[illegible]							
[illegible]	212,000	211,120	213,790	102,360	145,380	149,590	172,373
[illegible]	[illegible]	573,821	[illegible]	312,596	309,207	425,500	473,129
[illegible]							
[illegible]	3.00	2.72	2.72	3.05	[illegible]	2.84	2.75
[illegible]	[illegible]	306.8	268.2	341.3	283.8	332.0	295.7
[illegible]	71.20	70.17	62.63	69.02	48.96	66.27	65.81
Constituents (tons):							
[illegible]	50,272	50,993	49,933	26,760	27,871	38,837	40,779
[illegible]	11,993	13,114	12,258	6,941	6,437	[illegible]	10,002
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	92,547	111,633
[illegible]	37,356	[illegible]	[illegible]	17,005	19,707	24,859	[illegible]
[illegible]	137,882	134,098	[illegible]	68,515	71,118	[illegible]	[illegible]
[illegible]	234,084	213,541	186,231	[illegible]	94,627	[illegible]	[illegible]
[illegible]							
Composition (milligram equivalents):							
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.54	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.75	3.51
[illegible]	21.98	22.70	[illegible]	[illegible]	14.67	19.78	20.70
Sum (cations)	37.12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	32.91
[illegible]	[illegible]	4.15	[illegible]	[illegible]	[illegible]	4.01	3.99
[illegible]	9.96	9.73	[illegible]	10.25	7.81	10.17	9.53
Cl	22.87	20.95	18.04	20.26	13.48	18.96	19.31
[illegible]						.06	.04
[illegible]	37.08	34.83	31.37	34.51	24.56	33.20	[illegible]
[illegible]							
[illegible]	24	[illegible]	28	[illegible]	29	[illegible]	[illegible]
Magnesium	[illegible]	[illegible]	[illegible]	12	11	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	11	[illegible]	13	[illegible]	[illegible]	12	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	30	[illegible]	31	29
[illegible]	[illegible]	64	57	[illegible]	[illegible]	[illegible]	[illegible]

not shown in this summary table is that the concentration of the water passing the Courchesne station is much higher during the winter months than during the summer. This is doubtless due to the higher proportion of drainage water in the stream during the months when the gates at Elephant Butte Dam are closed.

Table 25 gives the mean annual data for the stations located at the head of the Tornillo canal, near Fabens, Tex., and at Tornillo Bridge, near Tornillo, Tex. The water samples have been taken at the head of the Tornillo canal and the discharge reported represents the discharge as measured into the canal, together with that of the river at Tornillo Bridge. The quality of the water sampled at this station is influenced by the drainage water returned to the stream above the sampling point. But not all of the drainage from land served by irrigation water diverted above Fabens gets back to the river above that point. For example, some of the water diverted from the river at El Paso into the Franklin canal is taken from that canal through the Island Feeder to supply land in the upper part of San Elizario Island. The drainage from that area is returned to the river below the Fabens-Tornillo station. At this station as at Courchesne the annual mean concentrations of the water fluctuates within a narrow range but monthly means, not shown in this summary table have a much wider range of fluctuation; the lower values occurring during the summer months.

The final table of this group, 26, shows the summary of conditions found at the Fort Quitman station. This station is located about 35 miles below the Elephant Butte project and all of the drainage from the lands of that project, as well as drainage from other irrigated land contiguous to the river, returns to the river above the station. The annual volume of discharge at Fort Quitman varies between wider limits than that at the stations between it and the reservoir and the concentration also is more variable. There is an inverse correlation between volume of discharge and concentration but it is not very close.

It remains now to review and discuss the conditions of discharge and salinity as found, for the 6-year period, at each of the five stations in the Elephant Butte project and to show the trends from station to station. Before proceeding to discuss the more important phase of this subject it seems proper to call attention to the conditions in respect to the seasonal volume of discharge of water at the several gaging stations. This may be considered in two ways, one relating to the characteristic monthly discharge and the other to the variations in annual discharge during the 6-year period ending with 1936.

It may be noted again that the purpose of Elephant Butte Reservoir is to regulate the supply of the Rio Grande so as best to serve the irrigation requirements of the land below it. Consequently, water is released from the reservoir only as it is required for irrigation use. In table 27 is shown for the year 1936 the percent-

age of the total annual discharge that passed each station in each month.

TABLE 27.—*The monthly discharges of water at 5 stations of Elephant Butte project, expressed as percentages of the total annual discharge for 1936*

Month	Elephant Butte	Leasburg Dam	El Paso (Courchesne)	Fabens-Tornillo	Fort Quitman
January	0.1	0.5	1.8	4.1	[illegible]
February	2.4	1.9	2.3	4.1	[illegible]
March	[illegible]	7.3	6.2	6.0	3.8
April	14.2	13.5	10.7	7.0	3.1
May	13.4	13.0	13.2	9.0	[illegible]
June	16.4	15.2	13.3	9.2	5.3
July	17.9	17.7	16.2	11.4	4.4
August	17.4	17.7	[illegible]	14.0	7.4
September	8.2	9.1	10.6	17.8	25.0
October	[illegible]	1.8	3.8	6.7	13.5
November	.8	1.3	2.6	6.3	9.2
December	.6	1.0	2.5	4.4	10.2
The year (acre-feet)	747,120	693,260	473,740	224,420	149,590

It will be seen that at the outlet of Elephant Butte Reservoir the monthly discharge was above 10 percent from April to August, inclusive, and that it was below 1 percent from October to January. The regimen was much the same at Leasburg Dam as at the reservoir outlet, for obvious reasons. At Courchesne the period during which the monthly discharge was above 10 percent extended from April to September, inclusive, and maximum percentage occurred in August, rather than in July, as at the reservoir. The lowest percentage was also in January, but it was 18 times as high as the percentage for that month at the reservoir. At Fabens the monthly discharge did not reach 10 percent of the total until July and reached its peak in September. At Fort Quitman the period of highest discharge extended from September to December. It is probable that the high percentages reported for Fabens and Fort Quitman for September 1936 may have been caused in part by the run-off of local rains. However, the evidence seems convincing that the irrigated land in each division of the project acts as a reservoir to equalize the discharge of the stream and to delay its peak at the lower stations.

The other aspect of the discharge regimen of the stream has to do with interannual variations at the several stations. This may be illustrated by the data of table 28. In this table the total annual discharge at each station is referenced to the mean annual discharge for that station for the 6-year period ending with 1936. It will be seen that the narrowest range of these percentages occurred at the reservoir outlet. This is to be expected. The greater significance of the table seems to be that the effects of the drought of 1934, with its consequent depletion of the reserve supply in the reservoir, were more pronounced and protracted at the lower stations of the project. This condition of affairs probably has an important bearing on the salinity conditions within the project.

In order to illustrate concisely the conditions of salinity within the project, attention may now be called to the data assembled in table 29. This table comprises the mean values for the 6-year period ending in 1936, in respect to the quantities of water and of dissolved solids passing each station, the concentration of the water, and the tonnage of each of the major constituents of the dissolved solids. The table shows that as the river flows from Elephant Butte Reservoir to Fort Quitman it loses water progressively. It loses, in fact, about 600,000 acre-feet annually. This water is presumably dissipated by evaporation and by transpiration from plants. The river apparently loses some dissolved solids also. The quantity lost between the reservoir and Fort Quitman has been about 150,000 tons annually. As a result of these respective losses the concentration of the water at Fort Quitman is approximately 3.5 times greater than at the reservoir.

TABLE 28.—*The annual discharge of water at the five stations of Elephant Butte project, expressed as percentages of the mean annual discharge for the 6-year period 1931–36*

Year	Elephant Butte	Leasburg Dam	El Paso (Courchesne)	Fabens-Tornillo	Fort Quitman
1931	98.0	99.0	99.1	108.9	123.0
1932	108.6	109.3	108.5	113.5	122.5
1933	107.9	110.6	116.5	127.8	124.1
1934	104.9	103.1	97.3	86.5	59.3
1935	83.1	84.9	88.0	76.0	84.3
1936	97.5	93.1	90.6	87.3	86.8

TABLE 29.—*The Rio Grande in the Elephant Butte project, New Mexico and Texas; discharge conditions at five control stations; means for 1931–36*

Item	Elephant Butte Outlet	Leasburg Dam	El Paso (Courchesne) station	Fabens-Tornillo station	Fort Quitman station
Discharge:					
Water (acre-feet)	766,131	744,982	522,758	257,123	172,373
Dissolved solids (tons)	619,909	647,406	637,968	496,014	473,129
Concentrations:					
Tons per acre-foot	0.809	[illegible]	1.22	1.93	2.75
Conductance	87.1	91.0	127.2	[illegible]	295.7
Sum (milliequivalents)	[illegible]	19.97	28.71	45.51	65.81
Constituents (tons):					
Calcium (Ca)	78,277	81,810	70,288	47,801	40,779
Magnesium (Mg)	[illegible]	17,876	[illegible]	[illegible]	10,002
Sodium (Na)	96,561	103,994	124,297	[illegible]	111,633
Bicarbonate (HCO3)	[illegible]	[illegible]	81,407	46,876	28,522
Sulphate (SO4)	234,731	238,989	[illegible]	135,317	[illegible]
Chloride (Cl)	[illegible]	72,392	112,716	126,776	160,924
Nitrate (NO_3)	349	1,289	1,661	[illegible]	611

It will be seen that the concentration increases progressively but not at a uniform rate for the three major divisions, and the loss of dissolved solids does not occur uniformly throughout the length of the project. Indeed, there is shown to be a gain in the total salt burden of the stream, as between the reservoir outlet and the Courchesne station, of nearly 28,000 tons annually. The losses of dissolved solids occur below that point; the indicated losses between Courchesne and Fort Quitman being approximately 165,000 tons annually. It is obviously not to be inferred that all of the dissolved solids shown to be lost from the stream between these two points are deposited in the soils of

the El Paso Valley division. The data available do not appear to warrant definite quantitive conclusions as to where these dissolved solids are deposited. But painstaking consideration of the available data and reviewing of the computations by which the summaries of table 29 have been obtained leads to the belief here stated, namely, that there is a very substantial quantity of soluble solids deposited annually somewhere along the Rio Grande between El Paso and Fort Quitman.

In view of this finding that there is a substantial loss of soluble solids from the Rio Grande as it flows through Elephant Butte project, it is pertinent to consider how this loss is allocated among the major constituents of these soluble solids. The data bearing on this question are also presented in table 29. In respect to the six major constituents and the total dissolved solids, expressing the quantities annually passing Fort Quitman as percentages of the quantities released from Elephant Butte Reservoir, we have the following:

Constituent	Percent
Calcium	52. 1
Magnesium	59. 0
Sodium	115. 6
Bicarbonate	30. 2
Sulphate	45. 7
Chloride	283. 6
Total dissolved solids	76. 3

It is manifest that there are great differences among these several constituents in respect to their transport along this section of the river. Referenced to the quantities released from the reservoir, there is a range from an apparent loss of 70 percent for the bicarbonate to an apparent gain of 183 percent for the chloride. Of the six constituents listed, four show losses and two show gains.

It was noted above that in respect to the total dissolved solids there was no loss but apparently a small gain occurring between Elephant Butte and Courchesne (El Paso). An inspection of table 29 shows that between the same points there are slight losses of calcium and magnesium, somewhat greater losses of bicarbonate and sulphate, and substantial gains of sodium and chloride. Between El Paso and Fort Quitman there are substantial losses of all constituents except chloride. These differences among the constituents in transport behavior are reflected, of course, in the percentage composition of the constituents as reported for these several stations in tables 22 to 26.

The question naturally arises as to the processes by which these changes in salt composition come about. If we had to consider only the relative quantities of total dissolved solids as between Elephant Butte and Fort Quitman, it could be assumed that a certain portion of the quantity passing the upper station was deposited in the soil somewhere between the two stations. In other words, that during the period of record there had been an adverse "salt balance" in the soil of the area of 146,000 tons per year. Or, to localize it more definitely as between Courchesne and Fort Quitman, it might be said that there had been deposited in the soil annually 165,000 tons of dissolved solids or during the last 6 years a total of 990,000 tons.

If we turn now to the evidence furnished by the data as to the several constituents, it becomes evident that the situation is not quite so simple as that. We have to deal with the fact that during the same period the quantity of the chloride constituent passing Fort Quitman has exceeded the quantity released from the reservoir by 104,000 tons annually, or 624,000 tons for the 6-year period of record. Conversely, to consider one other constituent, sulphate, the data indicate that the quantity passing Fort Quitman was less than the quantity released from the reservoir by 127,000 tons annually or 765,000 tons for the 6-year period. These facts do not fit into the simple theory of salt deposition in the soil.

We might attempt to explain the losses of tonnage for such constituents as calcium, bicarbonate, and sulphate by assuming that as a result of solution concentration in the soil these constituents were precipitated out of solution because they unite to form salts of low solubility. But no such line of reasoning may be invoked to explain the increase in the tonnage of chloride. Nor is this increase of chloride tonnage to be explained as coming into the area through tributary streams, because there are no streams of importance to bring it in.

We are thus forced to the conclusion that the increase in chloride tonnage passing Fort Quitman has originated within the area between that station and the reservoir. This conclusion, if it is warranted, has implications of profound significance. The most acceptable among the several theories that have been examined to explain these facts is one that may be designated the theory of displacement.

It was pointed out above that in respect to the seasonal inflow and outflow of water, each division of Elephant Butte Project seems to function as an equalizing reservoir. It is here suggested that this reservoir effect is indicated also in respect to inflow and outflow of the salt constituents. It is accepted as a fact that the valley through which the Rio Grande flows is a deep trough filled with sediments and that these sediments are saturated with water almost to the ground surface. Thus each division is thought of as a reservoir filled almost to the surface with ground water.

According to this theory of displacement it may be assumed that a substantial proportion of the water diverted from the stream and not dissipated by evaporation percolates through the subsoil to join the ground

water, and that instead of moving thence laterally along the surface of the ground water to the drains, it causes the ground water in the vicinity of the drains to rise into them as the result of hydrostatic pressures transmitted from the areas of freest percolation. Thus the inflowing river water, distributed through the irrigation system, replaces in part the ground water hitherto present in the subsoil and causes a corresponding quantity of ground water to pass out through the drains.

This theory seems not unreasonable and appears adequate to explain the known facts. Its validity, however, depends upon the existence of conditions not demonstrated by the present investigation. For example, the theory requires that the ground water hitherto present and assumed to be displaced by the surplus irrigation or percolating water shall contain very large quantities of chloride. It is necessary to explain the origin annually of 104,000 tons of chloride from within the area in question. The present investigation did not include an exploration of the deeper ground water in the sediments of the El Paso Valley. If subsequent investigation should show that these valley sediments do contain a large body of ground water with high chloride concentrations the theory of displacement would gain plausibility. On the other hand, if that condition could not be demonstrated the theory would be less acceptable.

The agricultural implications of the conditions here discussed merit consideration. If we could leave the main body of ground water out of account and assume that the surplus irrigation water percolating through the soil moved laterally to the drains, we might assume that the increase in chloride between the reservoir and Fort Quitman represented the removal of chloride from the soil. The annual removal of 104,000 tons of chloride from the root zone of 150,000 acres of irrigated land might be accepted as appreciable progress in reclamation or salinity removal, even if at the same time it was admitted that in respect to the total dissolved solids there was an adverse salt balance of large proportions. It could be suggested that the loss of total tonnage between the reservoir and Fort Quitman was to be explained as consequent upon the precipitation in the soil, in a harmless state, of the salts of low solubility.

It must be admitted, however, that such facts as are available do not appear adequately to support the view that the changes in chloride concentration of the water that occur between the reservoir and Fort Quitman are consequent upon phenomena that occur within the root zone of the soil and above the surface of the subsoil water. Were the theater of such changes as are indicated limited to the soil of the root zone, it seems inevitable that the evidence of their effect would be more apparent than is the case.

If we consider now the transport behavior of the sodium constituent we find that it does not follow that of either the chloride or the sulphate. There is an appreciable gain of sodium between the reservoir and Courchesne and only a slight loss between Courchesne and Fort Quitman. It is known that the cation constituents of these salts participate in reactions of base exchange in the soil. It seems highly probable that it is as a result of such reactions that the transport behavior of sodium differs so greatly from that of chloride, its natural associate. While no evidence is here presented to support the view, it seems probable that under existing conditions in the Elephant Butte project base exchange reactions are taking place on a large scale and that sodium is being absorbed by the soil of the root zone in place of calcium and magnesium.

In summarizing and reviewing these data concerning the concentration and composition of the dissolved solids carried by the Rio Grande through the Elephant Butte project the aim has been to show what the conditions are in the river itself. In presenting these findings it is hardly possible to avoid inferences or implications in respect to conditions in the irrigated areas served by the stream. Indeed, there has been no conscious attempt to do so. However, the investigations covered by this report have been limited to the quality of the surface and ground waters of the drainage basin. The aim has been to assemble, present, and interpret the available facts pertinent to this subject. What these facts may imply in respect to the problems of agricultural production on these irrigated lands is unquestionably a subject of importance but it is another subject.

PART IV

SECTION 7.—SALT CONCENTRATION AND SERVICE EQUIVALENCE

In the preceding chapter it has been shown that as the Rio Grande flows southward from its source in the mountains of Colorado, its water becomes progressively more saline until it passes out of the area at Fort Quitman, Tex. Throughout its course, water is diverted from the stream for irrigation. It is accepted as a fact that when irrigation water is applied to the land some of the water, usually the major portion of it, is evaporated from the soil or transpired by plants. The remaining surplus, if any, passes away either by downward percolation, or by moving laterally, escapes as subsoil drainage. Because of the losses by evaporation and transpiration, the residual water becomes more concentrated with the residual soluble material. Thus the soil solution in irrigated land is normally more concentrated than the solution with which the soil is irrigated.

Another accepted fact is that as the soil solution becomes increasingly charged with soluble material it becomes less suitable as a source of water supply for plants. It is probably not true that there is some "critical concentration" below which plants do well and above which they fail. There are, doubtless, optimum concentrations in respect to each constituent of the soil solution but these optimum concentrations are very low as compared to the concentrations which cause visible symptoms of plant injury or a serious impairment of growth. It seems unquestionable that when the salinity of the soil solution reaches concentration ranges that cause obvious plant injury conditions are far beyond any theoretical optimum and remedial measures are indicated.

In dealing with the subject of irrigation salinity, it should be kept in mind that the sphere of interest lies in the soil solution rather than in the irrigation water. It is easier to obtain samples of irrigation water than of the soil solution, consequently we know more about conditions in the former. We know also that the soil solution is always more concentrated than the irrigation water, but how much more so depends upon what proportion of the water applied to the soil surface ultimately percolates through the root zone and escapes below. As the proportion of the volume of root zone percolation to the volume of water applied increases, the difference between the concentration of the soil solution and that of the irrigation water diminishes. Consequently, because it is manifestly desirable to avoid injurious concentration of salinity in the soil solution, it follows that with more saline irrigation water it is necessary to apply larger quantities to the soil than would be necessary if the water were less saline.

These premises lead naturally to the question: What increase in application is required for a given increase in the salinity of the irrigation water in order that a given concentration of the soil solution should not be exceeded? The essential elements involved in this question may be defined and evaluated for any given situation and brought into an equation that illustrates the theoretical relationships.[1] There are at least 4 essential elements to be considered in this problem. These may be enumerated and described as follows:

(1) Consumptive use, i. e., the quantity of water, in depth per unit area required to support crop growth and meet evaporation losses. This may be designated as D_c.

(2) Irrigation requirement, i. e., the quantity of water, in depth per unit area required, not only for consumptive use, but also to provide sufficient percolation through the root zone to keep the concentration of the soil solution below a given maximum. This may be designated as D_a.

(3) Concentration of the irrigation water either in respect to total dissolved solids or in respect to any constituent regarded as potentially most likely to cause trouble. This may be designated as C_a.

(4) Concentration of the soil solution in the root zone, measured by the same standards or as to the same constituent as used for the irrigation water. This may be designated as C_r.

Whence the equation:

$$D_a = \left(\frac{2C_r}{2C_r - C_a}\right) \times D_c$$

To illustrate the application of this equation to a given area or situation, values may be assigned to three of the elements and values derived for the other one as follows: Let it be assumed that the consumptive use (D_c) for the situation is 2.00-acre feet per annum, and that the permissible limit of concentration of the soil solution (C_r) as measured by conductance is 400; then by means of the equation we may derive the irrigation requirement (D_a) for a series of values for various concentration of irrigation water (C_a).

With C_a as below (Conductance)	D_a (Acre-feet per annum)
87	2. 28
91	2. 29
127	2. 47
212	3. 13

[1] [illegible]

It may be observed that the values selected for C_i in the above list correspond with the mean conductance values of table 29 for 4 stations on the Rio Grande in the Elephant Butte project. These values as well as the assumption of 2.00 acre-feet for consumptive use (D_o) and the conductance value of 400 as the permissible limit of concentration of the soil solution (C_r) are used merely for purposes of illustrating the use of the service equivalence equation. It is not intended to imply that 2.00 acre-feet of water per acre is the requirement for consumptive use on the Elephant Butte project or that a conductance of 400 is the limit of concentration permissible for the soil solution of that area. The correct value to adopt for "consumptive use" in that area must be ascertained by appropriate inquiry and the value for the permissible limit of concentration of the soil solution (C_r) must be ascertained locally in the same way.

PART IV

SECTION 8.—THE SODIUM CONSTITUENT OF IRRIGATION WATER

In the tables of this report showing the detailed analyses of water the value of the sodium constituent has been reported not only in terms of milligram equivalents per liter but also as a percentage of the sum of the cations. The reason for including the second value is that the effect of sodium on the physical properties of the soil is believed to be related not to its absolute concentration in the solution but rather to its relative or proportional concentration.

It has been abundantly shown that the effect of sodium in solutions in contact with the soil is deleterious to the physical properties of the soil. This is brought about through reactions of base exchange by which sodium from the solution tends to replace calcium that is combined with the soil, the calcium in turn passing into solution. Such exchange reactions are well known and are extensively utilized in the zeolitic process of water softening.

The deleterious effects of sodium combined with the soil are manifested by dispersion of the soil particles, and by impairing the permeability of the soil to the absorption of water or the movement of water through it. Soils containing much combined sodium are also more difficult to work into good tilth than the same soils containing less combined sodium.

The extent to which sodium in the soil solution replaces calcium from the soil is influenced more by its relative concentration to calcium than by its absolute concentration. Therefore, it is believed that sodium percentage is a better expression of relative values between different waters than sodium concentration.

In the present state of our knowledge we do not feel warranted in setting a definite limit as the permissible sodium percentage of irrigation water. There is substantial agreement among those who have investigated the subject that, other things being equal, the lower the sodium percentage the better the quality of the water. It is also generally agreed that the same sodium percentage is likely to prove less harmful in waters of low total concentration than in waters of higher total concentration. Finally, it is generally agreed that sodium in irrigation water serves no useful purpose and that its presence in any concentration is to be regretted.

In view of these considerations, it may be observed that in respect to the criterion of sodium percentage the concept of service equivalence does not apply. The injurious effects of high sodium percentages are not to be minimized by applying larger quantities of water. It is possible, however, to offset these injurious effects either by adding a calcium salt such as gypsum to the irrigation water or by applying gypsum to the irrigated soil. To achieve the objective of service equivalence it might be necessary to introduce into the equation a cost factor by which to compensate for differences in sodium percentage between two water supplies.

PART V

WATER IMPORTATION AND STORAGE

Report of the United States Bureau of Reclamation[1]

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Section 1. Introduction and Summary

Section 2. New Mexico Investigations

Section 3. Colorado Investigations

[1] By W. G. [illegible]


GENERAL MAP

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DEPARTMENT OF THE INTERIOR

Harold W. Ickes, *Secretary*

BUREAU OF RECLAMATION

John C. Page, *Commissioner*
R. F. Walter, *chief engineer*
E. B. Debler, *hydraulic engineer, in charge of secondary investigations.*

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- E. N. Holmes.
- F. A. Ware.
- C. H. Howell.

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PART V

SECTION 1.—INTRODUCTION AND SUMMARY

Summary

New Mexico Investigations

San Juan-Chama transmountain diversion.—A mean annual yield (1924–35, inclusive) of 350,000 acre-feet can be diverted to the Chama River from a watershed area of 506 square miles above an elevation of 7,600 feet on the San Juan River and its tributaries.

Two plans have been considered, designated as plan A and plan B.

The estimated costs are as follows:

Plan A, $20,881,000; cost per acre-foot, $59.66.

Plan B, $17,500,000; cost per acre-foot, $50.00.

Terminal storage of 300,000 acre-feet to insure delivery to the Rio Grande of 350,000 acre-feet every year from 1911 to 1935, inclusive, without shortage, will cost for plan A an additional $1,350,000, and for plan B $2,500,000.

If San Juan and Chama River waters are regulated for power purposes only, a total head of 1,032 feet can be utilized and 250,000,000 kilowatt-hours of firm power, with large blocks of secondary power, developed annually, by the construction of four reservoirs on Willow Creek, two on the Chama, and utilizing the existing El Vado Reservoir, to provide a total storage capacity of 1,067,000 acre-feet.

Regulation of San Juan and Chama Rivers waters for power only, together with Rio Grande waters, would have produced a sufficient supply at Otowi for all irrigation requirements of the Middle Rio Grande conservancy district (1911–35, inclusive) except for a minor shortage in 1934.

Existing developments in the San Juan Basin as far down as Shiprock, N. Mex., will not be impaired by this diversion. Preliminary investigations indicate possible future extensions of areas to be served by the San Juan, totaling 30,000 acres, which will require 50,000 acre-feet of storage. A reservoir of 96,000 acre-feet capacity can be built on Weminuche Creek, a tributary of the Piedra, for $2,136,133, or $22.25 per acre-foot.

State-line reservoir.—Three possible dam sites were studied for this reservoir, all of which are geologically unfavorable for securing a tight reservoir but favorable for construction of a concrete dam. Ute Mountain site was finally selected as having better qualifications for an all-purpose reservoir. It is estimated to cost $2,600,750 for 452,000 acre-feet of capacity at elevation 7,500, or $5.75 per acre-foot.

Colorado Investigations

Animas-Rio Grande transmountain diversion.—A mean (1924–35) annual yield of 130,700 acre-feet can be diverted to the Rio Grande above the Rio Grande Reservoir for a total estimated cost of $10,432,500, or $79 per acre-foot, from a watershed area of 129 square miles above elevation 9,800 on the Animas River near Silverton.

The diversion system as planned comprises a reservoir of 54,000 acre-feet capacity at Howardsville, a tunnel through the Continental Divide 13 miles long, and a collection system 13.65 miles long, almost wholly of tunnel or concrete-lined conduit.

Existing and feasible developments on the Animas River below the diversion would have experienced no shortages of water in any month of any year since 1911, had the diversion been operating.

Weminuche Pass transmountain diversion.—An estimated mean annual yield (1924–35) of 20,455 acre-feet can be diverted through Weminuche Pass into the Rio Grande Reservoir for a total cost of $264,500, or about $13 per acre-foot, from a watershed of 24 square miles above an elevation of 10,500 feet on the headwaters of Pine River.

This mean yield is after allowance has been made for no diversions in 1925, 1931, and 1934, due to interference with storage development now authorized for construction on the Pine River project and after prior transmountain diversion rights of 4,000 acre-feet have been deducted.

San Juan-South Fork Rio Grande transmountain diversion.—A mean annual yield (1924–36) of 53,000 acre-feet can be diverted to the South Fork of the Rio Grande for an estimated total cost of $5,290,300, or about $98 per acre-foot, from a watershed area of 44.7 square miles on the headwaters of the San Juan River above an elevation of 9,050.

The diversion system consists of a feeder canal 2.6 miles long from the West Fork of the San Juan River to Beaver Creek, a tunnel 3.2 miles long from Beaver Creek to a junction with a 1-mile tunnel from Wolf Creek, and a tunnel 6.7 miles long from the junction to the South Fork of the Rio Grande. The total length of tunnels is 10.9 miles. Sites for regulating reservoirs have been located above this diversion, but from present data their inclusion in the project would increase the water yield but little and the project cost much more.

No existing rights on the San Juan below the diversion would be impaired, but the supply available for the San Juan-Chama diversion would be depleted by the amount diverted to the Rio Grande.

Conejos River storage.—Reconnaissance of the entire watershed resulted in the selection of four reservoir sites for intensive study, with results as follows:

No. 1 site.—Poor foundation conditions necessitate extreme conservatism in dam design. Estimated cost for a reservoir of 100,000 acre-feet is $3,700,000 or $37 per acre-foot.

Granite site offers more favorable foundation conditions but requires a high dam. Estimated cost for 100,000 acre-feet is $3,655,000 or $36.55 per acre-foot.

No. 6 site.—Favorable foundation and reservoir conditions permit construction for 32,000 acre-feet at total estimated cost of $608,400 or $19.01 per acre-foot.

Mogote.—An inland reservoir requiring a 5-mile feeder canal. Only fair geological conditions. For a capacity of 30,000 acre-feet the total estimated cost, including feed canal, is $746,100 or $24.87 per acre-foot.

Wagon Wheel Gap dam and reservoir.—A concrete arch dam at this site, to store 1,000,000 acre-feet of water, is estimated to cost $11,400,000, exclusive of railroad relocation and power installation. Potential power production at the dam will average 132,000,000 kilowatt-hours annually, all of which will be secondary power. Geologic conditions are favorable.

Vega Sylvester reservoir.—Foundation conditions are unattractive. Tentative designs and estimates for 240,000 acre-feet capacity show an estimated cost of $4,825,900.

Foreword

The Rio Grande rises in Colorado, flows across the entire State of New Mexico, then from El Paso to the Gulf of Mexico it becomes the international boundary between Mexico and the United States, and the southwestern border of Texas.

Irrigation developments in the San Luis Valley of Colorado consume all of the flow of the river and its tributaries except for the flood peaks and small winter flows. In northern New Mexico the stream is augmented by numerous partially used mountain tributaries, reaching a maximum flow in White Rocks Canyon opposite Santa Fe. The stream then enters the Middle Rio Grande Valley which ends at Elephant Butte Reservoir. Stream flow diminishes through Middle Rio Grande Valley despite flash floods contributed by numerous tributaries.

Waters are released from Elephant Butte Reservoir only as required for irrigation of the valley down to Fort Quitman, including a supply of 60,000 acre-feet annually for Mexican use by the terms of a treaty. The reservoir has not spilled since 1924 and was almost empty in 1935.

Below Fort Quitman, Tex., irrigation is largely confined to an area just above Brownsville, and mainly dependent on inflow below Fort Quitman.

Above Fort Quitman (according to the 1929 United States census), approximately 1,000,000 irrigated acres are dependent upon the river and its tributaries for their supply, about one-half of which are in Colorado, about 40 percent in New Mexico, and the balance in Texas.

Limited water supplies have, for many years, been the cause of many local and interstate controversies, extended litigation, arrested development, and unstable economic conditions.

A compact, ratified by the three States and the Federal Government in 1929, was in the main intended to arrest development pending further efforts to arrive at a permanent compact. This compact provided that not later than June 1, 1935, or such later date as might be agreed upon by the signatory States, a commission of four members, three appointed by the Governors of the respective States and one a representative of the President, shall equitably apportion the waters of the Rio Grande on the basis of conditions obtaining on the river and within the Rio Grande Basin at the time of the signing of the compact.

Experience gained by the Commission has increasingly demonstrated the need for a comprehensive study of the entire watershed and possible future developments within it, to assist them in making their decision. No methods of financing or conducting such a study were provided in the compact.

Creation of the National Resources Committee by Presidential order in 1934 brought into existence a central coordinating agency with power and authority to undertake just such investigation. The Compact Commission and the Resources Committee at once began negotiations for cooperation in the study. As a result, arrangements were finally perfected for participation of five agencies of the Federal Government with funds provided in part by the National Resources Committee, the cooperating agencies, and the interested States, all to be under the direction of the National Resources Committee. Each cooperating agency was assigned some portion of the investigations.

This report sets forth the accomplishment up to August 1, 1937, of that part of the Rio Grande joint investigation assigned to the Bureau of Reclamation.

Authorization and Cost

That part of the Rio Grande joint investigations undertaken by the Bureau of Reclamation, has been carried out under the terms of an agreement entered

into on February 28, 1936, between the National Resources Committee and the Bureau of Reclamation, which reads as follows:

In order to prepare a report on the Upper Rio Grande as contemplated in the request of the Rio Grande Compact Commission and in the allotment of funds to the National Resources Committee by the Public Works Administration, warrant no. 222, January 13, 1936, it is hereby agreed that:

(1) The Bureau of Reclamation will make such surveys and investigations (*a*) of reservoirs and dam sites in the basin of the Rio Grande, with designs and estimated costs of necessary dams and related structures; (*b*) of the possibilities of transmountain diversion of water from San Juan River and tributaries to the basin of the Rio Grande, including storage and the design and estimates of costs of all necessary conduits and works; and (*c*) of the possibilities and cost of hydroelectric developments in the basin of the Rio Grande, including its economic feasibility and the possible markets for and income from the electric power to be generated, as contemplated in work sheets filed with the National Resources Committee, which are subject to such modifications as may be mutually agreed upon between the Bureau of Reclamation and the National Resources Committee.

(2) To meet the cost of the work outlined in paragraph (1) above, including payment for salaries, expenses, subsistence, equipment, compilation of data, preparation of reports, supplies, and other purposes:

(*a*) *Contribution by Bureau of Reclamation.*—The Bureau of Reclamation agrees to make available from the funds allocated to the Bureau by the Emergency Administration of Public Works for the purposes herein set forth the sum of $30,000.

(*b*) *Contribution by National Resources Committee.*—The National Resources Committee agrees upon execution of this memorandum of agreement to advance to the Bureau of Reclamation from the funds made available to it by the Emergency Administration of Public Works for the purposes herein set forth the sum of $60,000 in accordance with section 601 of the act of June 30, 1932 (47 Stat. 417).

(*c*) *Reserved funds.*—It is understood that, in addition to the immediate allotment provided for in subparagraph (*b*) above, the National Resources Committee expects to develop a reserve fund from contributions to the project by other agencies or out of funds made available to it by the Emergency Administration of Public Works, such sums to be allotted by the National Resources Committee for the purposes of this investigation, if and as available, to meet expenses in connection therewith among the various agencies party to the Rio Grande joint investigations.

(3) *Reports.*—The Bureau of Reclamation agrees to finish the compilation of data and the preparation of necessary maps, diagrams, and specifications, and to file 100 copies of a complete report thereon with the National Resources Committee not later than January 1, 1937, or by such other date as may be mutually agreed upon between the parties hereto.

(4) *Reversion of funds.*—In the event of funds becoming available from other sources to the Bureau of Reclamation for any or either of the purposes set forth herein, or in the event the total sum made available to the Bureau by the National Resources Committee under this memorandum of agreement is not wholly expended, it is understood that such amounts as may be mutually agreed upon between the Bureau and the National Resources Committee shall revert to the reserve fund described in paragraph (2) (*c*) above.

A short time after the above agreement had been signed, the Committee made the following allotments and priorities:

New Mexico investigations:	
1. San Juan-Chama diversion	$35, 000
2. State Line Reservoir	15, 000
3. Willow Creek or other terminal reservoir	5, 000
Total	55, 000
Colorado investigations:	
1. Wagon Wheel Gap Reservoir	10, 000
2. Conejos River Reservoir	9, 000
3. Vega Sylvester Reservoir	3, 000
4. San Juan-South Fork (Rio Grande) diversion	8, 000
5. Animas-Rio Grande diversion	14, 000
6. Navajo-Conejos diversion	1, 000
Total	45, 000

No part of the reserve fund set up in the agreement became available to the Bureau of Reclamation.

In October 1936, an additional sum of $50,000 was made available for continuation of the work, from other P. W. A. funds.

Situations developing in the course of the work made allotment shifts desirable. All deviations were fully discussed with the various interests and approved by them before authorized by the Committee or its representatives.

Unsatisfactory foundation conditions disclosed at the dam site proposed on the Conejos River made it advisable to give consideration to several additional dam sites. Diversion of Pine River waters through Weminuche Pass was suggested, and this feature was added to the investigation. A paper study of the proposed Navajo-Conejos diversion quickly proved that plan to be infeasible. Several alternative surveys on the San Juan-Chama diversion were found advisable. Additional dam sites for the State Line Reservoir were investigated. Preliminary studies of power possibilities at Wagon Wheel Gap Dam and on Willow Creek and the Chama River were made.

Expenditures as of July 1, 1937:	
Surveys—general	$6, 147. 39
Wagon Wheel Gap Dam	13, 193. 66
Conejos River Dams	19, 973. 67
Vega Sylvester Dam	5, 523. 80
San Juan-South Fork Rio Grande diversion	3, 689. 65
Animas-Rio Grande diversion	5, 436. 97
San Juan-Conejos diversion	236. 22
State Line Dam and reservoir	20, 394. 05
Willow Creek Dam	290. 38
San Juan-Chama diversion [1]	47, 323. 12
Total	122, 208. 91
Plant and equipment	11, 187. 80
Total	133, 396. 71

[1] [illegible]

The item of plant and equipment represents ledger values of engineering, prospecting, and transportation equipment, the remaining value of which will be credited to the project as it is transferred to other work.

Estimated costs upon completion of the authorized program, with credit allowances for returned equipment, and distribution of general costs, compare with the net allotments as follows:

	[illegible]
Utilization of San Juan River waters within its basin in Colorado and New Mexico	$9,000
New Mexico:	
San Juan-Chama diversion	52,000
State Line Reservoir	21,000
Willow Creek Reservoir	1,000
Subtotal	74,000
Colorado:	
Wagon Wheel Gap Dam	16,000
Conejos River Reservoirs	23,000
Vega Sylvester Dam	7,000
San Juan-South Fork (Rio Grande) diversion	5,000
Animas-Rio Grande diversion	5,700
San Juan-Conejos diversion	300
Subtotal	57,000
Grand total	140,000

Conduct of Work

Initial surveys, dam site exploration, and geological examinations were begun at Wagon Wheel Gap and Vega Sylvester dam sites late in April 1936. On May 1, 1936, two surveying crews were started on the San Juan-Chama diversion. Thereafter, from four to six crews were employed continuously until July 1, 1937, except for a 6-weeks lay-off in February and March 1937, due to extreme bad winter weather. Diamond drill rigs were moved on to the Wagon Wheel site in July 1936, and after completing the work at that site and Vega Sylvester, started work on the Conejos River site. The rigs were released to Western Slope surveys during the latter part of September and returned to drill at the State Line site on December 1. Additional drilling on Mogote Reservoir, Conejos River, and State Line sites, was continued until April 15, 1937. A churn drill rig started work on the Conejos site in July 1936, and finished at the upper West Fork site in October of that year.

Test pit crews were working at Vega Sylvester site in April, Conejos site in June, and on the four sites on the San Juan River until late in November 1936, when they moved to the Mogote site. Thereafter, they worked on the State Line and Stinking Lake sites until February 1, when this part of the work was discontinued.

Four-man plane-table survey parties, consisting of the instrumentman, a recorder, and two rodmen, were used on all reservoir and dam topography. Transit parties comprised a transitman, a flagman, two chainmen, and an axman. Only one transit party was used on canal location, while on strip topography, and on reservoir surveys, there were at times five plane-table parties at work.

Each diamond drill was worked two shifts, the crews comprising a driller and two helpers on each shift. The churn drill was worked two shifts part of the time, but only one shift for the remainder. One driller and one helper comprised the crew for each shift.

Surveying crews and geologists used five station wagons and three sedans; the diamond drill crews had a 1½-ton truck and a pick-up available. Occasionally an additional truck was hired for transporting material and equipment for the test pit and churn drill crews. Pack outfits were utilized for the Animas-Rio Grande and Weminuche Pass surveys.

A summary of the work accomplished by the surveying crews is as follows:

Summary of surveys:
- Dam-site topography, 5-foot contours: Scale, 50 feet to 1 inch. 27 sites surveyed.
- Reservoir topography, 5-foot contours:
  - Scale, 1,000 feet to 1 inch, 5 covering 27,579 acres.
  - Scale, 200 feet to 1 inch, 5 covering 3,965 acres.
- Canal fly line (transit and stadia or plane table), 234 miles.
- Canal location, transit and chain, 150 miles.
- Strip topography for canals and roads, 5-foot contours. Scale 200 feet to 1 inch, 104 miles.
- Tunnel triangulation, approximately, 25 miles.
- Reservoir triangulation, approximately, 25 miles.
- Levels, approximately, 350 miles.

All water supply studies were made in the Denver office with the assistance of some of the field men brought in after field work was shut down.

Canal estimates and designs were made by the Canal Section under the direction of H. R. McBirney of the Denver office.

Dam estimates and designs were made in the Denver office by the Dams Section under the direction of W. E. Blomgren. Vega Sylvester dam designs and estimates were made under the direction of F. F. Smith.

A subforeman handled all of the test pit crews, working on as many as three dam sites at one time. All pits were cribbed with timber framing. Two 4-horsepower gasoline single-drum hoists were used for hoisting. Percolation tests were carried out at most of the pits using a 3-inch centrifugal pump direct connected to a 6-horsepower gasoline engine.

One 75-pound sample of material from each 5 feet of pit was taken. These samples, together with all cores secured by the diamond drill rigs, are stored in the warehouse of the Farmers Union Ditch Co. near Del Norte.

Expenditures on dam-site explorations have amounted to about 28 percent of the total amount spent on the investigation. The exploration work accomplished may be summarized as follows:

Type of work	Number of holes	Number of sites	Total footage	Average depth of hole	Average field cost per foot
Diamond drilling	31	11	[illegible]	[illegible]	$4.49
Churn drilling	7	4	913	130	[illegible]
Test pit	[illegible]	9	1,114	[illegible]	[illegible]
All types	77	....	[illegible]	85	5.48


WEST FORK RESERVOIR
EAST FORK RESERVOIR
PLAN A
PLAN B
TUNNEL

PART V

SECTION 2.—NEW MEXICO INVESTIGATIONS

San Juan-Chama Transmountain Diversion

General Description

Figure 100 is a general map showing the various features of the plan herein outlined for the diversion of San Juan River water to the basin of the Chama River, a tributary of the Rio Grande.

Early Surveys

In 1933, a reconnaissance survey was made for the San Juan-Chama diversion. This line was run at an elevation of about 8,000 feet, beginning at the East Fork of the San Juan River to the Navajo River, where it dropped to elevation 7,800, thence across the Continental Divide about 12 miles west of Chama, discharging into Willow Creek, a tributary of the Chama River on the south side of the Divide. Surveys of a part of the reservoir sites on the West Fork, East Fork, Blanco, and Navajo, adopted for the present plan, were also made. The diversion point of the canal was so high that waters of the West Fork of the San Juan could not be utilized except with a pumping lift of about 200 feet.

Two plans have been considered in some detail in the 1936–37 surveys, herein designated as plans A and B.

Plan A

Surveys of 1936 began with retracement of the line originally proposed, except for the last 6 miles in the East Fork Basin. A reconnaissance for a line at a lower elevation was started at the same time which soon disclosed possibilities justifying a survey along this route which developed into plan A. Although plan A was found to be higher in first cost than the 1933 line, the additional water secured more than offsets the difference in cost. Topography was then taken on the line for plan A with 5-foot contours covering a strip reaching 25 feet above and 50 feet below the tentative line elevations. This survey was started on July 20 and completed by October 23. The preliminary lines were run with horizontal control by transit and chain, which control was transferred to planetable sheets and used by the topographic parties. Vertical control was based on United States Geological Survey benchmarks with elevations taken from published bulletins. Between New Mexico and Colorado, a discrepancy of from 5 to 7 feet was found in the United States Geological Survey elevations. The original datum at Monero was carried throughout the surveys.

In locating lines A and B, special consideration was given to lines that would offer low maintenance risks, avoid questionable side slopes, and give the shortest possible routes. Many cases of alternative routes were met. At important cross-drainages it was always necessary to make a decision between a route up one side and back the other, or to go straight across with a long siphon. Sometimes both lines were surveyed and the final location selected on the basis of lowest cost. In general, though, when time did not permit a detailed study of the alternatives, the decision was in favor of a route which appeared to offer the least hazards in operation, even though the cost might be considerably greater.

Plan A involves the diversion of Turkey Creek (a tributary of the San Juan River) into a reservoir of 70,000 acre-feet capacity on the West Fork of the San Juan River about 14 miles north of Pagosa Springs, Colo. From the bottom of this reservoir a diversion canal of 300-second-foot capacity carries Turkey Creek and West Fork waters to a 70-foot drop into East Fork about 1 mile above its confluence with the West Fork. About 6 miles upstream a reservoir of 35,000 acre-feet capacity is planned to regulate the flow of the East Fork.

A diversion dam a short distance below the canal drop into the East Fork, diverts into a canal of 500 second-foot capacity which lies just above the 7,500 contour east of the San Juan River. Coal Creek, Mill Creek, Rito Blanco, and the Blanco River are diverted into the main canal by short feeder canals. Five and a half miles above the Blanco River crossing, a reservoir of 15,000 acre-foot capacity is planned to regulate the flood flows of that river. From the Blanco River to the Little Navajo River the canal capacity is increased to 700 second-foot and is almost entirely in tunnel. At the lower portal of the tunnel on the Little Navajo River the canal is joined by a diversion canal from the Navajo and Little Navajo Rivers and its capacity is again increased to 800 second-feet.

After passing a few miles along the westerly side of the Little Navajo River, the main Navajo River is crossed with a siphon almost a mile long under 350 feet maximum head. At the end of the siphon the canal enters a succession of tunnels and siphons on the south side of the Navajo River to a point about 1½ miles east of Edith and almost on the Colorado-New Mexico boundary line. Continuing almost due south

the canal traverses several deep cross drainage streams, crosses Amargo Creek and the Denver & Rio Grande Western Railroad (narrow gage) near Monero, N. Mex., and finally enters a 6-mile tunnel under the Continental Divide beneath Hillcrest on the Jicarilla Indian Reservation. From the lower portal of this tunnel at an elevation of 7,400 feet the water flows in a natural stream bed to Boulder Lake.

Plan B

Following completion of the plans and estimates for plan A, consideration was given to the possibilities of a less costly route, as a result of which plan B was surveyed, and estimates prepared, although not with the same detail as plan A.

Plan B starts with the same reservoir on the West Fork of the San Juan River, except that the outlet is 82 feet higher, with an increase in dead storage of 10,000 acre-feet. The reservoir was not enlarged to offset this increase in dead storage. Turkey Creek diversion is common to both plans. The East Fork of San Juan River is crossed with a 700-foot siphon at the lower end of which East Fork waters are received from a short diversion canal, thus saving an additional 70 feet in elevation over the A line. Line B is on a slightly lighter gradient to conserve head for the purpose of shortening the tunnels. Lines A and B are closely parallel from the East Fork of San Juan River to Little Navajo River, with a difference in elevation increasing from 140 to 160 feet. The feed canals used in plan A from Coal Creek, Mill Creek, Rito Blanco, and Rio Blanco, are eliminated as the line at this higher elevation permits crossing these streams at grade. At Little Navajo River, line B deflects to the east to cross Navajo River on grade and then passes southward to cross the Continental Divide immediately west of Chama and very close to the crossing of the Divide by the Denver & Rio Grande Western Railroad Co. Between the Navajo River and Chama summit a long tunnel is required to penetrate a high mesa around which no practical route could be found. While line B intercepts slightly less drainage area than line A, no difference has been made in the canal capacity as the difference in run-off would be negligible. One advantage of plan B over plan A is the higher level for delivery of waters into the Chama River watershed, plan B making such delivery at elevation 7,575 and plan A at elevation 7,401, a difference of 174 feet in favor of plan B, which will be useful in power production. Furthermore, plan B entails lesser length of costly structures as indicated by the following comparison.

Greater accessibility along the entire route of plan B also offers distinct advantages. The new highway now being built between Chama and Pagosa Springs will be within 1 mile of the entire route between the Blanco River and Chama Summit.

The four reservoirs, viz, West Fork, East Fork, Blanco, and Navajo, are common to both plans.

	Plan A	Plan B
	Miles	Miles
[illegible]	35.07	[illegible]
[illegible]	8.08	13.41
[illegible]	4.04	[illegible]
[illegible]	17.03	[illegible]
[illegible]	.46	[illegible]
[illegible]	[illegible]	81.72
[illegible]	[illegible]	9.33
Total	[illegible]	91.05

Design and Estimate Data

Earth canal is proposed for cross slopes up to 20° with the horizontal and combination concrete-lined sections for heavier slopes. Bench flumes with vertical side walls are proposed for sidehill location in rock. Tunnel sections are of horseshoe shape and concrete lined throughout. Tunnel estimates are based on providing steel rib and timber lagging supports for their entire length as they are thought to be located in shale and loose material. Sandstone may be encountered in some places, in which case supports probably would not be needed and construction costs lessened.

Canal excavation is divided into two classes: Class 1 being earth and loose rock requiring no blasting; and class 2 being rock and shale requiring blasting.

Figure 101 shows typical sections for the component parts of the canal system. The only railroad service into the territory is over the narrow-gage line of the Denver & Rio Grande Western Railroad Co. from Alamosa to Durango. The A line crosses this railroad at Monero at canal milepost 50, and B line about 12 miles east of Monero. Shipping points will be either Monero, Lumberton or Chama, in New Mexico. The route of the A canal is never more than 3 miles from improved roads. Above Pagosa Springs, the canal line parallels an oiled highway. From Pagosa Springs to Navajo River the highway is either graveled or will be within a few months. Below Navajo River, the dirt roads that must be used with plan A often become impassable with mud. South Fork, Colo., on the Creede branch of the Denver & Rio Grande Western Railroad Co. from Alamosa, is the nearest (29.5 miles) shipping point for the north end of the work with an excellent highway between.

Estimates—Plan B

Time did not permit line B to be surveyed in the same detail as line A. The cost for much of line B was based on the cost per foot of comparable sections of line A, using equal unit costs and suitably revised quantities. The estimate for line B is as follows:

TABLE 1.—*San Juan-Chama transmountain Diversion, plan A, quantities and unit costs*

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
MAIN CANAL								
Excavation:								
Canal:								
Common	3,963,520	Cubic yard					$0.15	$594,528
Rock	937,210	Cubic yard					.75	702,910
Structure:								
Common	4,645	Cubic yard					.75	3,484
Rock	3,505	Cubic yard					3.00	10,515
Tunnel, 9.5-foot diameter, 925 to 3,820 feet long, all classes	35,100	Cubic yard					8.00	280,800
Tunnel:								
9.5-foot diameter, 10,625 feet long, all classes	40,590	Cubic yard					9.00	365,310
11.0-foot diameter, 29,350 feet long, all classes	151,150	Cubic yard					11.00	1,662,650
11.5-foot diameter, 400 to 7,646 feet long, all classes	60,220	Cubic yard					7.50	451,650
Tunnel, 11.5-foot diameter, 29,873 feet long, all classes	168,185	Cubic yard					11.00	1,850,035
Trimming foundations	129,560	Square yard					.45	58,303
Backfill	37,030	Cubic yard					.25	9,258
Puddling backfill	4,820	Cubic yard					.50	2,411
Concrete:								
Canal lining	107	Cubic yard					15.75	1,685
Combination section	22,221	Cubic yard					17.25	383,363
Bench flume	2,120	Cubic yard					18.75	39,750
Structure	1,350	Cubic yard					21.75	29,362
Monolithic siphon barrels	12,419	Cubic yard					21.75	270,114
Siphon piers and anchors	4,844	Cubic yard					19.75	95,669
Tunnel lining:								
9.5-foot diameter	18,423	Cubic yard					13.75	253,316
11.0-foot diameter	37,862	Cubic yard					17.25	653,120
11.5-foot diameter	15,188	Cubic yard					13.75	208,835
11.5-foot diameter	42,420	Cubic yard					17.25	731,745
Steel:								
Reinforcement:								
Siphons, structures	5,491,400	Pound					.055	302,029
Piers and anchors	451,800	Pound					.06	27,108
Ribs	5,030,250	Pound					.08	402,420
Gates	5,000	Pound					.15	750
Hoists	1,500	Pound					.30	450
Welded pipe	10,375,650	Pound					.09	933,809
Tunnel drains	9,185	Linear foot					1.50	13,777
Do	66,580	Linear foot					2.50	166,450
Timber	4,000.1	M board measure					80.00	320,008
Riprap	125	Cubic yard					1.50	188
Right-of-way	794	Acre					20.00	15,880
Clearing	465	Acre					25.00	11,625
Farm crossings		8					200.00	1,600
Do		25					250.00	6,250
Do		4					300.00	1,200
Do		20					400.00	8,000
Farm turnouts		28					250.00	7,000
Do		15					325.00	4,875
Highway crossings		1					3,000.00	3,000
Do		3					2,000.00	6,000
Drainage inlets		22					160.00	3,520
Do		15					200.00	3,000
Do		65					225.00	14,625
Do		60					275.00	16,500
Diversion of East Fork, San Juan	[1]							800
Property damage	[1]							2,500
								10,932,177
FEEDER CANAL								
Diversion:								
Diversion at [illegible] Creek		[1]						4,900
Structure excavation:								
Common	800	Cubic yard					.75	[illegible]
Rock	750	Cubic yard					3.00	2,250
Backfill	650	Cubic yard					.25	160
Puddling backfill	650	Cubic yard					.50	325
Structure concrete	905	Cubic yard					21.75	19,686
Riprap	405	Cubic yard					1.50	609
Reinforcement steel	72,400	Pound					.055	3,982
Gates	23,000	Pound					.15	3,450
Hoists	7,600	Pound					.30	2,280
Excavation:								
Canal:								
Common	680,800	Cubic yard					.15	102,120
Rock	175,250	Cubic yard					.75	131,437
Tunnel, 6.5-foot diameter, 1,800 feet long, all classes	3,200	Cubic yard					15.00	48,000
Trimming foundations	65,300	Square yard					.45	29,385
Concrete:								
Combination section	13,090	Cubic yard					17.25	225,803
Structure	40	Cubic yard					21.75	870
Tunnel lining, 6.5-foot diameter	790	Cubic yard					23.00	18,170
Steel:								
Reinforcement	1,260,000	Pound					.055	69,300
Ribs	27,800	Pound					.08	2,224
Tunnel drains	1,800	Linear foot					1.50	2,700
Timber	24.9	M board measure					80.00	1,992
Right-of-way	335	Acre					20.00	6,700
Clearing	290	Acre					25.00	[illegible]
Farm crossings		13					150.00	1,950
Do		12					200.00	2,400
Farm turnouts		2					200.00	400
Do		10					250.00	2,500

[1] Lump sum.

TABLE 1.—*San Juan-Chama transmountain Diversion, plan A, quantities and unit costs*—Continued

Item	[illegible]		Material and labor furnished by the contractor		Material furnished by the Government		[illegible]	
	[illegible]	Unit	[illegible]	Total cost	Unit cost	Total cost	[illegible]	Total cost
[illegible]								
[illegible]		[illegible]					$2,500.00	[illegible]
[illegible]		[illegible]					160.00	[illegible]
[illegible]		[illegible]					[illegible]	[illegible]
								717,158
[illegible]								[illegible]
Contingencies, [illegible] percent								[illegible]
Total [illegible]								[illegible]
[illegible]								50,000
[illegible]								[illegible]
[illegible]								[illegible]
[illegible]								[illegible]
Total estimated cost								11,7[illegible]

Main canal	West Fork, San Juan River to East Fork, San Juan River, length in feet	Capacity, 300 second-feet, cost
Earth canal	15,500	[illegible]
Combination section	2,000	[illegible]
Siphons	700	42,000
Subtotal	18,200	126,815

[illegible]	East Fork, San Juan River to Rio Blanco	Capacity, 500 second-feet
Earth canal	[illegible]	[illegible]
Combination section	[illegible]	[illegible]
Siphons	[illegible]	0
Tunnels	11,100	[illegible]
Subtotal	171,500	[illegible]

[illegible]	[illegible]	[illegible] second-feet, cost
Earth canal	[illegible]	[illegible]
Combination section	[illegible]	[illegible]
Siphons	[illegible]	[illegible]
Tunnels	[illegible]	1,937,312
Subtotal	[illegible]	[illegible]

Main canal	[illegible]	[illegible]
Earth canal	[illegible]	[illegible]
Combination section	[illegible]	300,600
[illegible]	0	[illegible]
Tunnels	[illegible]	4,783,455
[illegible]	0	0
Subtotal	[illegible]	5,549,655

Subsidiary diversions

[illegible] (same as for plan A)	$370,241
East Fork	126,500

Subsidiary diversions—Continued

Coal Creek, Mill Creek, and Rito Blanco	7,590
Little Navajo River	12,650
Navajo River	20,240
Subtotal	539,751

Summary of costs—Plan B

Main canal		$10,860,666
Subsidiary diversions		539,751
Reservoirs:		
West Fork	$2,069,588	
East Fork	1,449,306	
Blanco	1,060,494	
Navajo	1,515,138	
		6,094,526
Grand total		17,494,943
Cost per acre-foot of annual yield (350,000 acre feet)		50

Water Supply

The general map, figure 99, shows drainage lines and the location of all run-off and rainfall stations at which any records at all have been secured. A list of gaging and rainfall stations and a diagram showing the length of record secured at each of them is given in figure 102. United States Geological Survey quadrangle sheets are available for the entire watershed in Colorado, but in New Mexico no reliable topographic maps are in existence. These records comprise all of the basic data from which the available run-off in the San Juan Basin must be estimated. The dearth of run-off and rainfall records in the areas affected by the transmountain diversions necessitated developing methods of estimating the same from available records. Figure 102 shows that for the 10-year period of 1916–25 there are more

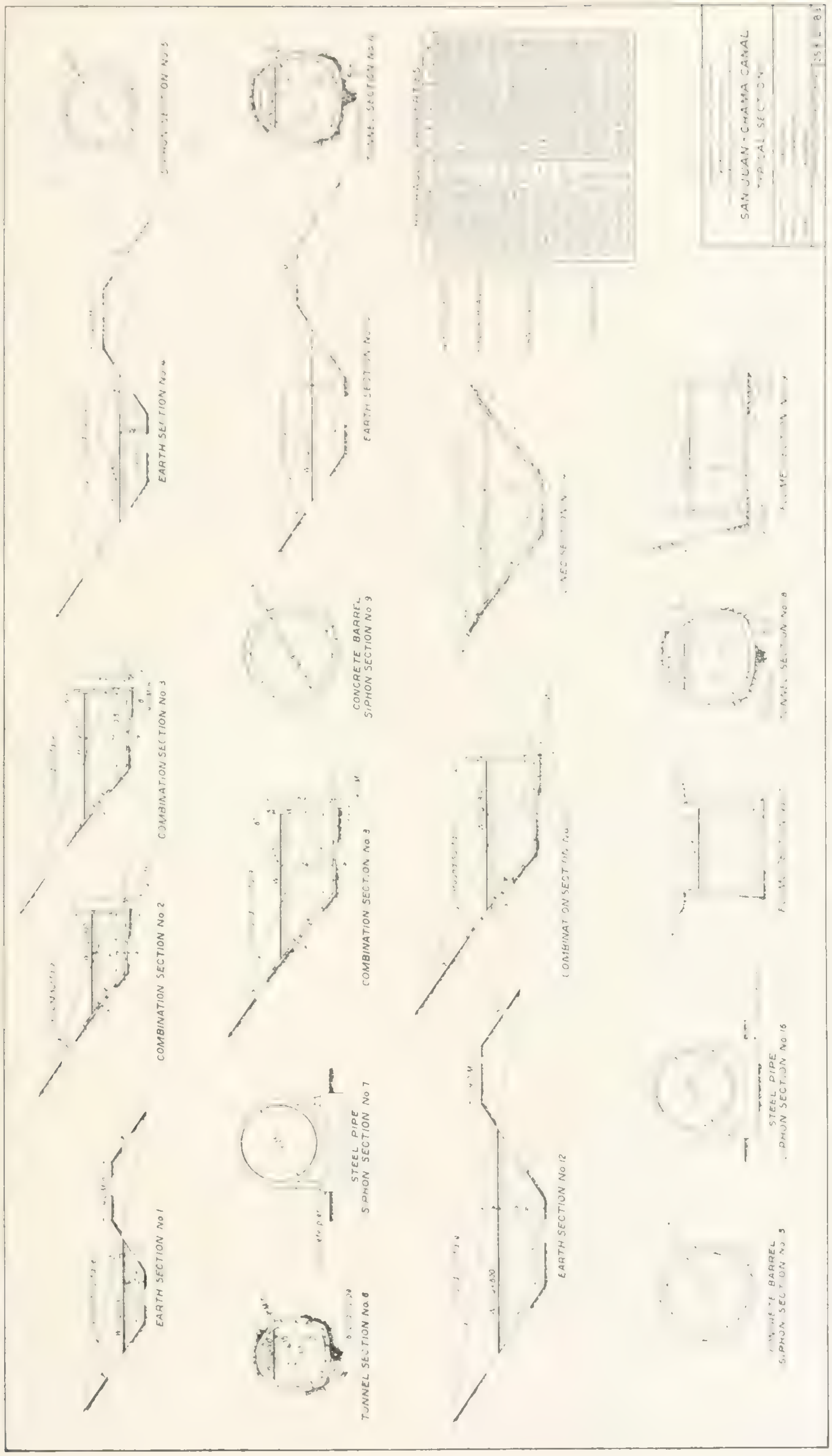

EARTH SECTION No 1
COMBINATION SECTION No 2
COMBINATION SECTION No 3
EARTH SECTION No 4
STEEL PIPE
SIPHON SECTION No 7
COMBINATION SECTION No 8
CONCRETE BARREL
SIPHON SECTION No 9
EARTH SECTION No 12
STEEL PIPE
SAN JUAN-CHAMA CANAL

FIGURE 101

complete concurrent data than for any other period. This cycle was therefore selected as a base for making all other determinations.

Two methods have been tried, described herein as the rainfall-altitude and run-off altitude methods, respectively.

Rainfall-altitude method.—The procedure adopted in using this method is as follows:

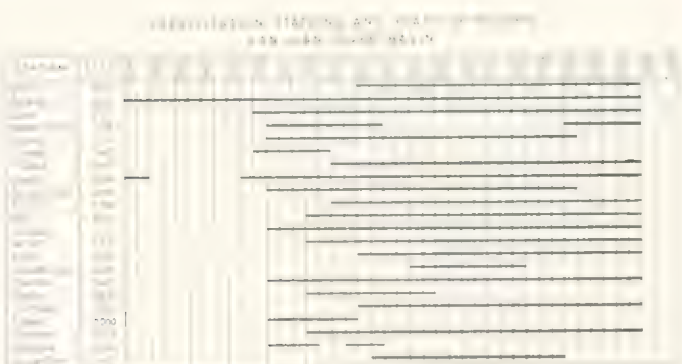
(*a*) Determine mean run-off at each gaging station for the period 1916–25 in acre-feet per square mile of tributary watershed area.

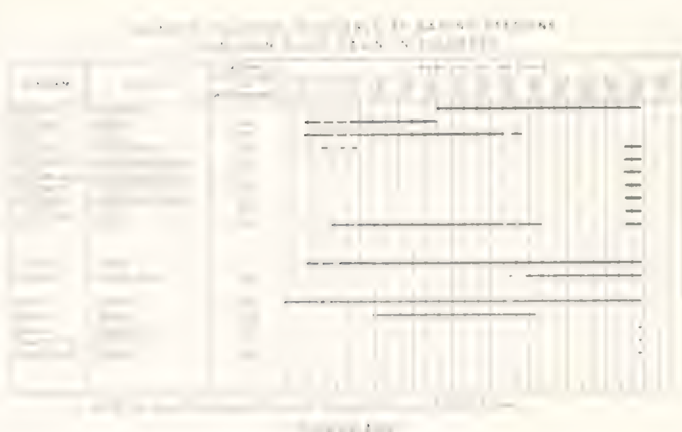
(*b*) Calculate mean rainfall for each station within or adjacent to the drainage area above the run-off station.

(*c*) Plot mean rainfall for each rainfall station against its altitude and draw a curve through the points which averages them as near as possible. Mean rainfall at any elevation can then be taken from the curve.

(*d*) From topographic maps determine the area of the watershed between each 500-foot contour.

(*e*) Multiply each area between 500-foot contours by the mean rainfall (taken from the curve) for the average elevation of that band. The sum of these products divided by the total area gives the mean rainfall for the watershed.





(*f*) Rainfall less run-off gives the "consumptive use" or the residue of rainfall after it has been subjected to evaporation and transporation losses except for underground waters leaving or entering the basin.

Run-off for each 500-foot band can then be computed by assuming "consumptive use" to be constant for all elevations and subtracting this constant from rainfall in each case.

Run-off for individual years can be determined by the same procedure but the method does not lend itself readily to determination of monthly stream discharges. This procedure was carried out for both the Animas River above Tacoma and the San Juan River above Arboles, with fairly satisfactory results when the 10-year mean was used but when an effort was made to break it down to individual years, the rainfall points on the diagram were so badly scattered that it was difficult to draw a curve which would justify confidence in the results.

Run-off altitude method.—The same period, 1916–25 was used for determining means. Procedure was then as follows:

(*a*) Mean unit run-off in acre-feet per square mile was determined for three stations on the San Juan River, the Navajo River at Edith, three stations on the Animas River, and the Pine River at Bayfield (in part derived from Ignacio).

(*b*) Watershed areas above each gaging station were divided into bands of 500 feet difference in elevation in

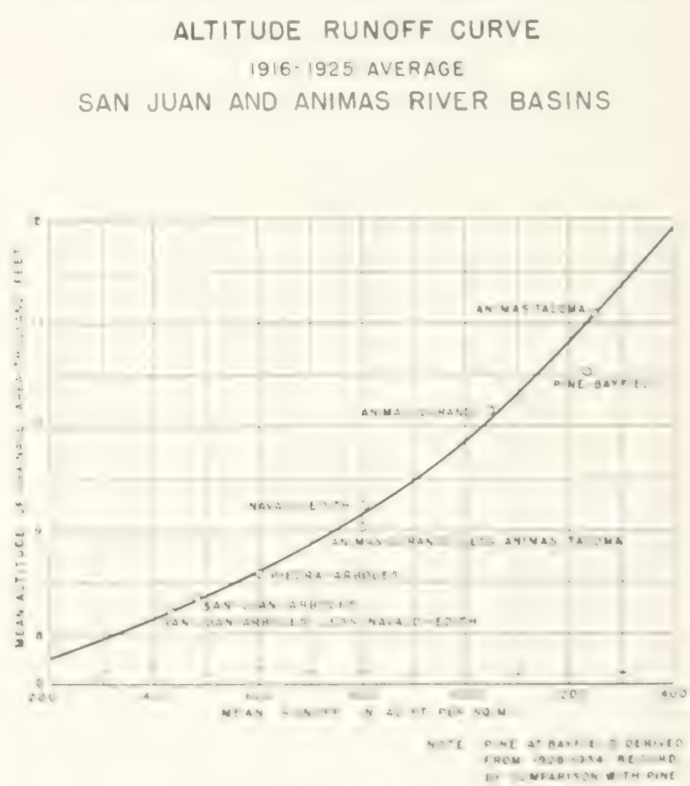


FIGURE 103

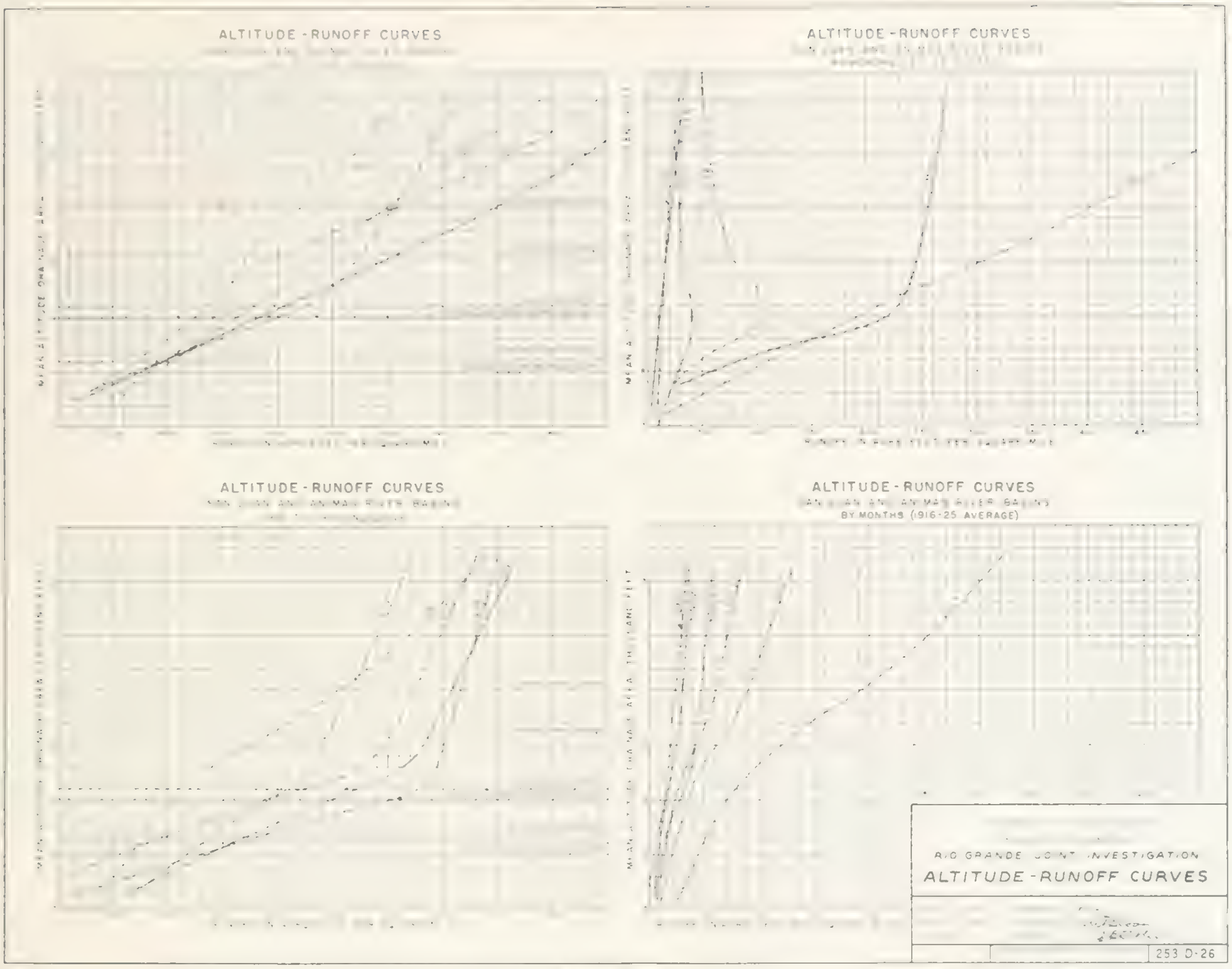


FIGURE 104

the manner heretofore described for determining mean rainfall.

(*c*) Unit run-off for each gaging station was then plotted against mean altitude and a curve drawn through the points.

The resulting curve is shown in figure 103. The points are well scattered from low to high elevations and departures from the mean are small. The greatest departure is for the Pine River at Bayfield and this influence was recognized by modification of the curve when used for the Pine or the San Juan Rivers.

By this method two run-off records on the same watershed enable three points to be calculated for the curve; one for the area above the higher station, another for the entire area above the lower station, and the third for the area between.

The same procedure was followed in determining the run-off for any watershed for individual years and even for individual months for any particular year. In practically all cases, the points were so near the mean curve drawn through them that the results appear to be as reliable as can be obtained with so little record data available. Details of the application of this method to each of the watersheds studied in the investigation are given in the report on each feature.

Extensions of run-off estimates from 1926 to date, where necessary, were made by correlating the short-term record at the station in question with that of a station with a long-time record in periods of concurrent record. It is recognized that the resulting discharges are to a large degree estimates and it is hoped that arrangements can be made to establish and continuously operate gaging stations found to be desirable in connection with projects deemed likely to be constructed.

The total area contributing to the diversion is 506.24 square miles with a mean altitude of 9,688 feet. From figure 103 mean run-off at this altitude is found to be

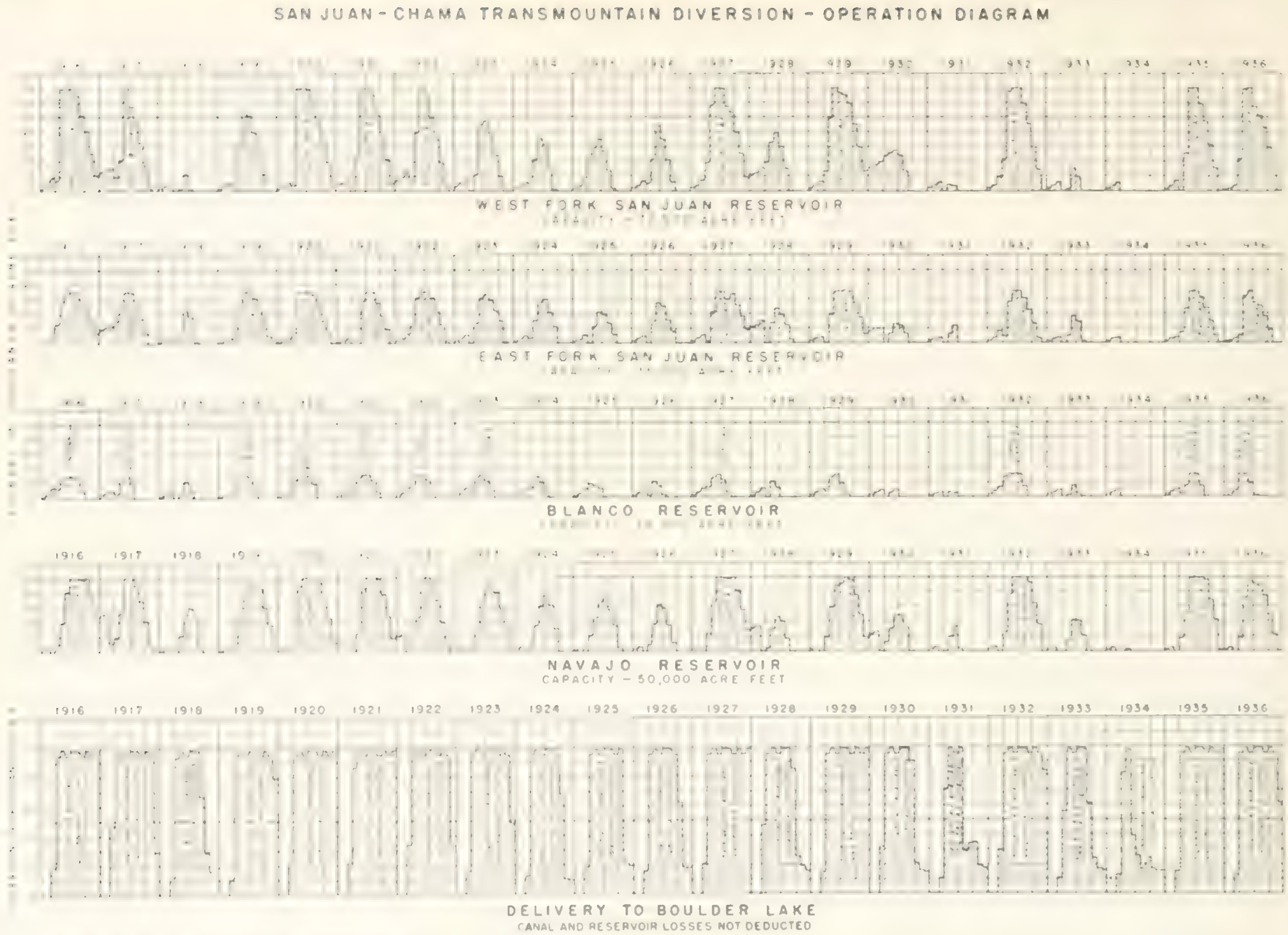


FIGURE 105

970 acre-feet per square mile, or a total of 486,200 acre-feet.

Operating studies of capacities for reservoirs and canals made it necessary to determine the monthly discharges in any year. The altitude-run-off method was found to be admirably adapted thereto, the curves for which are also shown in figure 104. Total average annual run-off for 1916-25 estimated from the altitude run-off curves compare as follows:

	Acre-feet
[illegible] fig. 104	486, 200
[illegible] fig. 104	479, 920
Mean of sum of monthly discharges for entire area from fig. 104	469, 620
[illegible] from fig. 104	478, 650
Average	478, 598

The only long-term record on San Juan River is that at Rosa, N. Mex., which is below all streams proposed to be diverted and also below the mouth of the Piedra River. Monthly discharge for the years 1926 to 1936, inclusive, were estimated with correlation curves based on concurrent records of monthly discharges during the years 1916–26 for each of the watershed areas tributary to the canal and the reservoirs. The area of each of the watersheds as compared to the area above Rosa is so small, however, and Rosa is so remote from the areas considered, that the results can only be considered approximations, although the best that can be secured with the available data.

Required canal and reservoir capacities were determined by trial operations. Small diversion canals were designed for a capacity 50 percent in excess of the mean daily discharge for the maximum mean month during the period 1916–25. Reservoir capacities were sometimes fixed by the physical limitations at the dam site and in other cases by the capacity necessary for the adopted operating schedule. A number of possible combinations of canal and reservoir capacities were studied with the one here presented found to be the most practical of any tried. Below the Navajo River canals were considered to be in operation each

month except January and February. All other canals are assumed to be incapable of operation in the months of January, February, and March. Necessarily, capacity cannot practicably be provided to capture all water available in high years, but the amounts escaping are not excessive. The operations are graphically presented on figure 105.

The 1916–36 mean of divertible supply is 380,860 acre-feet with no allowances for losses in transit or from the reservoirs. The reservoirs are full for about 2 months out of the year. The maximum total area of the reservoirs, excepting Boulder Lake, is 1,850 acres. With an estimated evaporation rate of 2 feet in depth per year (new losses in excess of existing uses on the same areas), the loss would be 3,700 acre-feet per annum. Seepage losses from the reservoirs would probably be recovered in every case except for the West Fork Reservoir as the canal diversions are so far downstream from the dams. The total length of unlined canal is about 52 miles. Canal losses would be offset in part by contributions from areas in New Mexico tributary to the main canal not included in the estimates of water supply. A 5-percent net loss through seepage should probably be anticipated, or a total of 20,000 acre-feet per annum.

Local Requirements in the San Juan Basin

The San Juan River at Shiprock, N. Mex., has a drainage area of 12,738 square miles and a mean discharge of 2,500,000 acre-feet per annum. Land classification studies being made as a part of the Colorado Basin investigation under section 15 of the Boulder Canyon Act show that within this area there was irrigated in 1933 a total of 104,743 acres of land, of which 32,228 acres were in New Mexico, and 72,515 acres in Colorado. Irrigation on the San Juan River and its tributaries above the San Juan-Chama diversion is practically nonexistent. Below the diversion and down to Arboles, a total of 2,245 acres is irrigated from the San Juan River and its tributaries. Below Arboles there are but 8,162 acres being served from the San Juan River. The balance is irrigated from tributaries. Bahmeier found an additional area of 2,567 acres of arable land above Arboles, all of class II character. Not over 360 acres of this area can probably be feasibly irrigated. With enough water left to supply 2,600 acres, the balance can be diverted without injury to existing irrigation projects. Waters rising below the diversion line, together with losses from the canal will hold necessary bypasses to negligible amounts for these lands.

TABLE 2.—*Water supply—San Juan-Chama transmountain diversion* [1]

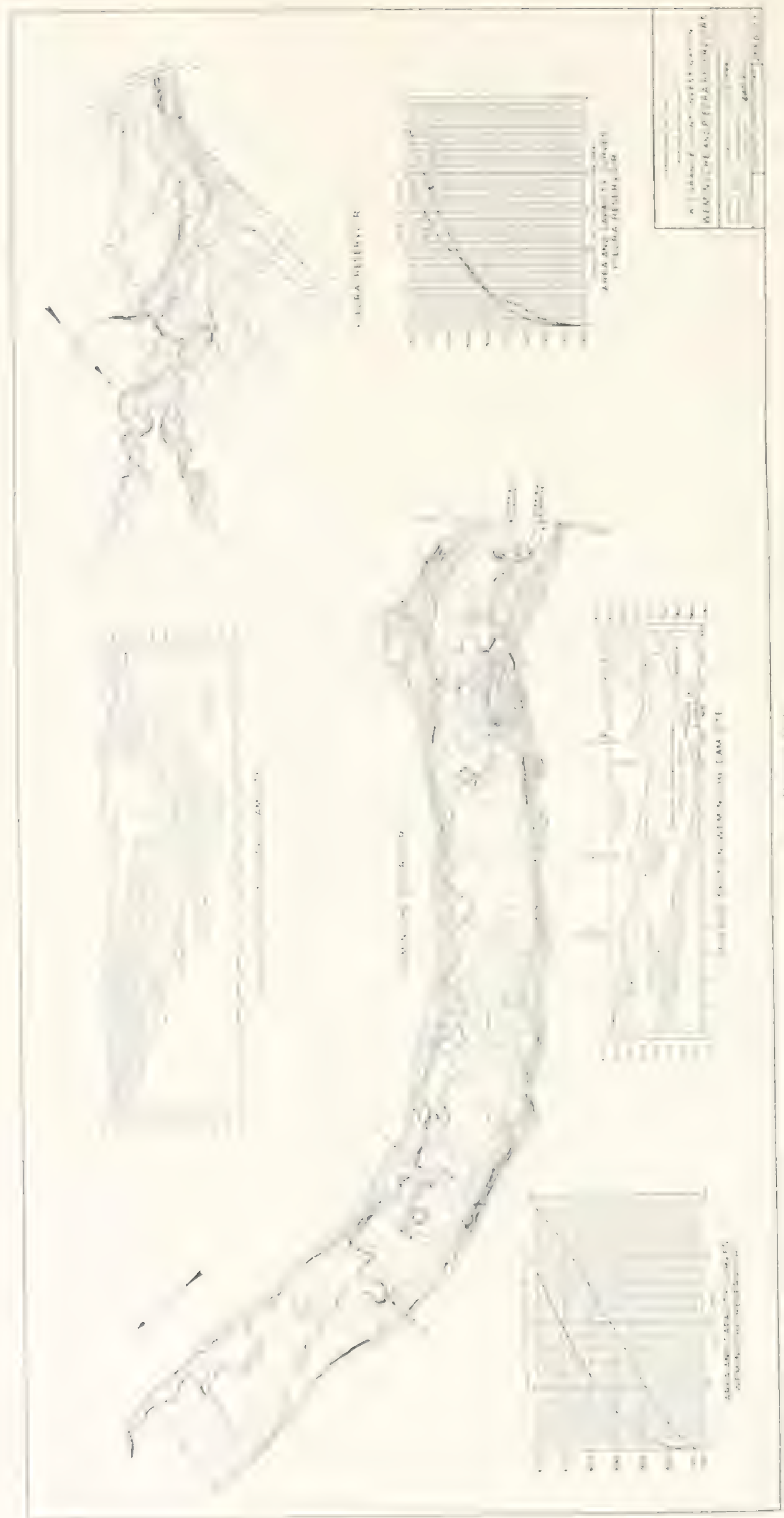
[All quantities in thousands of acre-feet]

Year	Unregulated supply			Inflow to reservoirs					Releases from reservoirs					Spill from reservoirs					Gross delivery to Boulder Lake	Total waste [5]	Maximum storage			
				San Juan					San Juan					San Juan							San Juan			
	Total [2]	Diverted	Waste [3]	West fork [4]	East fork	Blanco	Navajo	Total	West fork	East fork	Blanco	Navajo	Total	West fork	East fork	Blanco	Navajo	Total			West fork	East fork	Blanco	Navajo
1916	190.14	159.61	30.53	189.12	76.34	85.39	75.12	524.64	120.72	44.03	78.22	43.30	286.27	58.16	24.71	7.17	8.63	98.67	445.88	105.43	70.00	35.00	15.00	50.00
1917	170.51	140.53	29.98	104.38	59.07	73.13	64.40	300.98	113.80	47.77	44.40	78.99	284.96	.82	18.90	28.73	8.60	57.05	425.49	74.49	70.00	35.00	15.00	50.00
1918	92.20	83.01	9.19	83.28	51.33	47.41	48.63	230.65	83.28	51.33	47.41	48.63	230.65	0	0	0	0	0	313.66	0	10.76	21.82	10.76	29.58
1919	149.46	137.85	11.51	112.68	62.22	68.16	59.93	302.99	112.68	57.50	64.39	59.93	294.50	0	4.72	3.77	0	8.49	432.45	9.80	53.30	35.00	15.00	44.63
1920	238.32	185.68	52.64	163.94	94.57	104.68	94.26	457.45	113.79	55.22	36.27	57.35	262.63	47.28	39.35	68.41	30.88	185.92	448.31	216.42	70.00	35.00	15.00	50.00
1921	146.88	136.08	10.80	139.19	74.46	78.50	76.74	368.89	123.88	70.51	50.83	62.15	307.37	13.37	3.95	27.67	11.74	56.73	443.45	58.87	70.00	35.00	15.00	50.00
1922	165.19	124.56	40.63	124.87	68.33	75.00	65.88	334.08	112.47	48.14	63.63	71.75	295.99	17.21	20.19	11.37	3.00	51.77	420.55	81.15	70.00	35.00	15.00	50.00
1923	141.07	126.87	14.20	112.98	58.20	63.01	59.71	293.90	112.98	58.20	61.88	59.71	292.77	0	0	1.13	0	1.13	419.64	1.13	47.39	32.21	15.00	44.26
1924	124.78	111.14	13.64	84.24	47.22	51.16	47.81	230.43	84.24	47.22	51.16	47.81	230.43	0	0	0	0	0	341.57	0	35.45	29.49	13.40	37.79
1925	108.39	97.57	10.82	100.08	56.28	57.04	58.80	272.20	100.08	56.28	57.04	58.80	272.20	0	0	0	0	0	369.77	0	34.46	21.47	8.33	37.26
1926	118.75	107.13	11.62	92.26	47.72	51.90	49.10	240.98	92.26	47.72	51.90	49.10	240.98	0	0	0	0	0	348.11	0	44.35	27.50	10.14	30.60
1927	192.07	153.42	38.65	140.81	76.68	83.00	76.90	377.39	101.23	53.10	80.65	58.25	293.23	31.12	14.25	2.35	5.00	52.72	446.65	77.75	70.00	35.00	15.00	50.00
1928	111.23	96.16	15.07	80.97	43.16	45.70	42.50	212.33	89.43	52.49	45.70	56.15	243.77	0	0	0	0	0	339.93	0	38.75	23.15	10.35	23.15
1929	168.61	145.77	22.84	129.42	68.51	74.10	68.30	340.33	106.93	60.15	74.10	56.60	297.78	9.12	1.41	0	2.40	12.93	443.55	24.85	70.00	35.00	14.15	[illegible]
1930	97.15	87.45	9.70	83.60	42.18	45.80	41.70	213.28	96.97	49.13	45.80	51.00	242.90	0	0	0	0	0	330.35	0	26.93	12.53	4.30	23.85
1931	83.63	75.24	8.39	66.72	36.82	40.60	35.20	179.34	66.72	36.82	40.60	35.20	179.34	0	0	0	0	0	254.58	0	5.43	10.57	2.80	16.50
1932	184.60	142.12	42.48	143.38	80.04	86.70	85.10	395.22	102.06	56.29	69.85	73.65	301.85	41.32	23.75	16.85	10.35	92.27	443.97	114.30	70.00	35.00	15.00	[illegible]
1933	90.07	81.33	8.74	83.04	40.76	44.00	39.60	207.40	83.04	40.76	44.00	39.60	207.40	0	0	0	0	0	288.73	0	14.77	18.14	7.40	21.30
1934	64.95	55.00	9.95	39.50	26.50	28.10	24.00	118.10	39.50	26.50	28.10	24.00	118.10	0	0	0	0	0	173.10	0	5.91	2.89	3.50	2.40
1935	162.63	130.70	31.93	143.10	77.55	82.20	77.40	380.25	121.36	48.65	69.77	73.30	313.08	21.74	28.90	12.43	4.10	67.17	443.78	88.72	70.00	35.00	15.00	50.00
1936	118.78	108.53	10.25	127.10	66.66	68.72	73.00	335.48	124.60	61.19	57.23	73.00	316.02	2.50	5.47	11.49	0	19.46	424.55	19.46	70.00	35.00	15.00	47.48
Mean annual diversion																			380.86					

[1] No reservoir or canal losses subtracted in this table.
[2] Supply from tributaries unregulated by reservoirs including Turkey Creek for January, February, and March, when canal is not operated.
[3] Includes waste during months canals not in operation and undivertible peak flows.
[4] Includes flow from Turkey Creek, April–December, inclusive.
[5] Reservoir spill plus undivertible peak flows only.

The mean annual net delivery of regulated water to the Chama River above El Vado Reservoir is then estimated at 350,000 acre feet.

The Piedra, Pine, Florida, and Animas Rivers enter the main San Juan River below Arboles and adequately supply the 8,162 acres now irrigated.



The Vallecito Reservoir with a capacity of 124,000 acre-feet soon to be constructed on Pine River will reduce flood flows of the San Juan River but return flow from the project may actually increase some of the late season discharges at the mouth of the Pine River and on the San Juan River below.

While the extent of future development on the lower San Juan is not definitely known, it is, nevertheless, certain that some storage for regulation of the flood flows will be needed to enable complete irrigation development. The Arboles site on the San Juan just below the mouth of the Piedra River has been surveyed but not explored. Geologists report a poor quality of sandstones and shales in the abutments with little possibility of satisfactory foundation at reasonable depth. The site was originally contemplated for a reservoir of 1,500,000 acre-feet capacity. A considerable part thereof would need to be set aside for silt.

During the summer of 1937, two dam and reservoir sites were surveyed on the Piedra River and its tributary, Weminuche Creek, the results of which are shown on figure 106. The reservoir on the Piedra River would have a capacity of 52,000 acre feet with a dam 245 feet high. It will obviously have a high cost per acre-foot of capacity. On Weminuche Creek, a capacity of 140,285 acre-feet can be secured with a dam 160 feet in height but estimates of run-off available at the site indicate that no more than 96,000 acre-feet of capacity is justified. The estimated cost of a dam and reservoir for this capacity is $2,140,000, or $22.25 per acre foot, including the diversion of Williams Creek into Weminuche Creek, the latter diversion being necessary to justify the capacity of 96,000 acre-feet.

The following are estimates of the mean annual flow of Weminuche Creek, Williams Creek and the Piedra River above the proposed dam sites for the period 1916 to 1925, inclusive.

	Acre-feet
Weminuche Creek at proposed reservoir	41, 850
Williams Creek above diversion to Weminuche Creek	40, 600
Piedra River above proposed reservoir	88, 830

Over 50 percent of the present irrigation development on the lower San Juan River is served by canals diverting from the Animas River itself or from the San Juan River below the mouth of the Animas River.

Incomplete surveys within the San Juan River Basin under the provisions of the Boulder Canyon Project Act, indicate a probable increase of about 30,000 acres in the irrigated area in the future, in addition to completion of development under existing ditches, south of San Juan River, mainly below Farmington. A storage capacity of as much as 50,000 acre-feet may be needed for this area, and can be secured within the Piedra watershed. Possibly an equal area may be developed along the lower portion of the Animas River and westward along the north side of San Juan River. This area can best be served by storage on Animas River with the Animas reservoir site at Durango, often mentioned in such connection. Utilization of the upper San Juan River waters for any purpose would have no bearing on Animas River plans. Florida River lands expect to secure some water from Vallecito reservoir and must in any event look to Florida River for any additional supplies needed.

It is concluded, therefore, that diversion of San Juan River waters to the Chama River would not injure the future development of the San Juan Basin although with more extensive development than now anticipated it may become proper for the diversion project to assist in storage development for San Juan Basin use, to offset diversion of waters which could be locally used. No interference seems possible under present conditions.

West Fork Reservoir

The dam site is located on the West Fork of the San Juan River about 4 miles above its junction with the East Fork in section 29, T. 37 N., R. 1 E., of Mineral County, Colo. and about 12 miles northeast of Pagosa Springs. An alternative dam site 3 miles downstream, known as the Lower West Fork site, was investigated but found less desirable by cost and elevation.

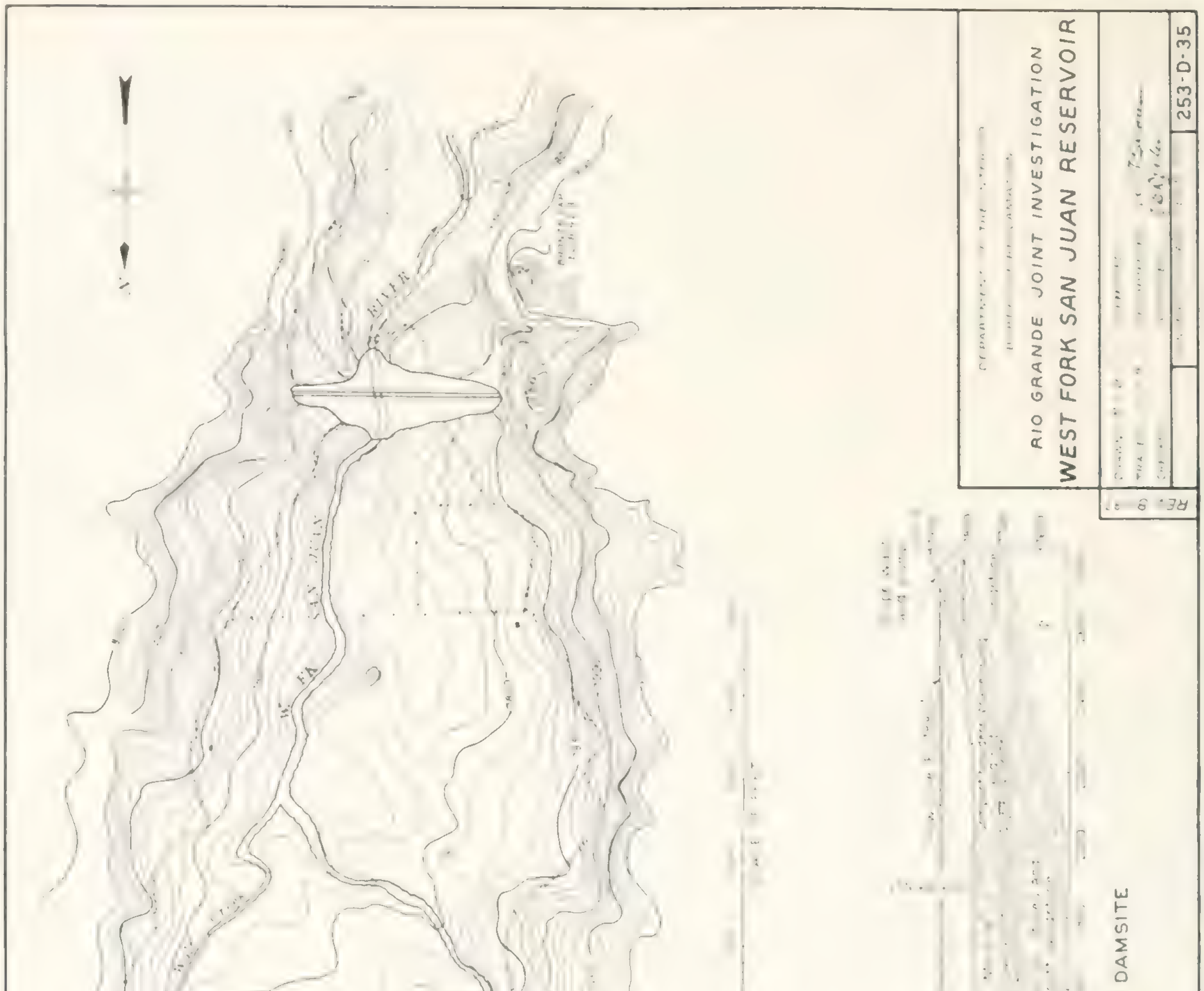
A storage capacity of 70,000 acre-feet is required for regulation of the West Fork waters.

Summary of estimate data:

Storage capacity	70,000 acre feet.
Spillway capacity	13,000 second feet.
Regulated outlet capacity	300 second feet.
Elevation—top of dam	7,888.
Normal and maximum water-surface elevation.	7,880.
Height of dam above stream	160 feet.
Total estimated cost—dam and reservoir.	$2,069,588.
Preliminary estimate	Table 3.
Reservoir topography and geologic section.	Fig. 107.
General plan and sections	Fig. 108.

The reservoir area at elevation 7,880 covers 1,100 acres of privately owned lands. No clearing will be required. The nearest shipping point is South Fork, on the Creede branch of the Denver & Rio Grande Western Railroad 29.5 miles away.

West Fork Reservoir geology.—Almost the entire watershed is of igneous flow rock containing little soluble material. The basin is a normal erosional valley carved through these flow rocks (andesite) into underlying shales and sandstones. None of the bedrocks are exposed in the valley floor nor will the flow lines contact any of the igneous rocks. The beds lie approximately horizontal. There are signs of faulting but it is believed that no recent movements have occurred.


RIO GRANDE JOINT INVESTIGATION
WEST FORK SAN JUAN RESERVOIR
253-D-35
AREA - CAPACITY CURVES
GEOLOGIC SECTION AT DAMSITE

In the basin, the underlying shales and sandstones are heavily mantled with a variety of detrital materials. Occasional knobs of glacial debris rise above the stratified sands and gravels laid down by the stream. On the sides, thick wash and slough areas are progressively overriding the bottom gravels.

Vegetative cover on the floor of the basin consists of wild hay meadows, scattered spruce and cottonwood trees, while the sides are more heavily timbered with oak, brush, aspens, spruce, and pine. A water table tributary to the river is indicated by spring and seep occurrences. It is believed that reservoir losses can only occur by seeping down the valley in the sands and gravels overlying the relatively impervious bedrock.

West Fork dam site geology.—The dam site occupies a portion of the valley narrowed by deposition of extensive morainal material in which the stream is now flowing (fig. 107).

The right abutment is a chaotic mass of andesite boulders, cobbles, sand, and silt, somewhat lensed, but probably relatively impervious when considered as a whole, as disclosed by three test pits (nos. 1, 1a, and 2) (fig. 108) on which percolation tests were run. One drill hole (no. 1) indicates that between the morainal material which was found to be 20 feet thick, and the underlying shales, there is a 78 foot layer of sands and silts which was evidently a lake deposit later overridden by the moraine.

On the left abutment the morainal material has been and is progressively being covered with a compact slough and wash material of angular rock and fragments embedded in silt, eroded from the adjoining hills. This mantle wedges out on the moraine exposed at the river bank. Material eroded from the side hills appears to be more compact and impervious than the morainal deposit. Again, as on the right abutment, a drill hole (no. 2) disclosed a layer of loose sand and gravel beneath the morainal deposit but much thinner (23 feet).

The moraine terminates upstream and downstream on the stream axis outside the foundation limits of the dam itself, thus leaving exposed to percolation the rather loose porous sand and gravel strata found beneath the moraine on the dam axis. The percolating distance is adequate to preclude heavy or dangerous leakage.

Dam.—This dam site is known as the upper site. The lower site is about 3 miles downstream, or about a mile above the confluence of the East and West Forks. Planetable topography was secured at the lower site in 1936 and at the upper site in 1937. Rough estimates disclosed that a dam for the same reservoir capacity at the lower site would be much more expensive than one at the upper site and would not permit diversion for the canal in plan B without pumping.

Figure 108 shows the general plan and sections for the proposed dam at the upper site. The proposed section for the dam is of the compacted embankment type with a deep cutoff trench. Sufficient rock is placed on the downstream slope to protect the embankment and the rather steep abutments against sloughing. The dam is 2,500 feet long on top and attains a maximum height of 160 feet at the river crossing. Ample embankment borrow material is believed to be available within a mile of the site. Sand and gravel deposits occur about one-half mile upstream from the site but have not been analyzed. Adequate sand proportions may be lacking.

The entire foundation will require surface stripping. The material from the cutoff trench excavation can be used in construction of the downstream portion of the embankment.

Spillway.—The drainage area of the reservoir, exclusive of the Turkey Creek intercepted area is 83 square miles. A spillway with a maximum capacity of 13,000 second-feet is to be constructed on the glacial moraine formation near the left end of the dam, as bedrock will not be available. A radial gate structure was adopted to provide an 8-foot freeboard without raising the dam. Three automatic radial gates 20 feet long by 17 feet high and of substantial construction to withstand ice pressure are proposed. The gate structure is of reinforced concrete, counterfort and cantilever wall construction. The spillway channel is of concrete cantilever wall construction. A roadway is provided over the dam and spillway, to connect with the proposed relocation of U. S. Highway No. 160.

Outlet works.—For outlet and diversion purposes a 12-foot standard horseshoe tunnel of liner plate and concrete lining construction is provided under the left abutment of the dam. The bottom of the trash rack is placed above the tunnel to keep sand and gravel out of the completed tunnel, provide protection for fish, and to prevent complete draining with unsightly exposure of the reservoir bed.

A gate chamber containing one 57-inch ring follower emergency gate is placed just upstream from the axis of the dam. A 57-inch steel pipe leads down the tunnel from the gate chamber to the single 48-inch needle valve. The needle valve house contains the necessary pumps, piping, cranes, etc., required for operation. A gas-driven generator set is planned for lighting and operation of the valves and spillway gates. The needle valve discharges into the spillway stilling basin. The outlet crest of the stilling basin is placed at elevation 7,724 in order to control the flow into the outlet canal. The water surface in the canal is at elevation 7,723.5.

Construction.—It will require approximately 3 years to construct the dam and appurtenant works. There is no local power available for construction purposes. Estimate of cost is given in table 3.

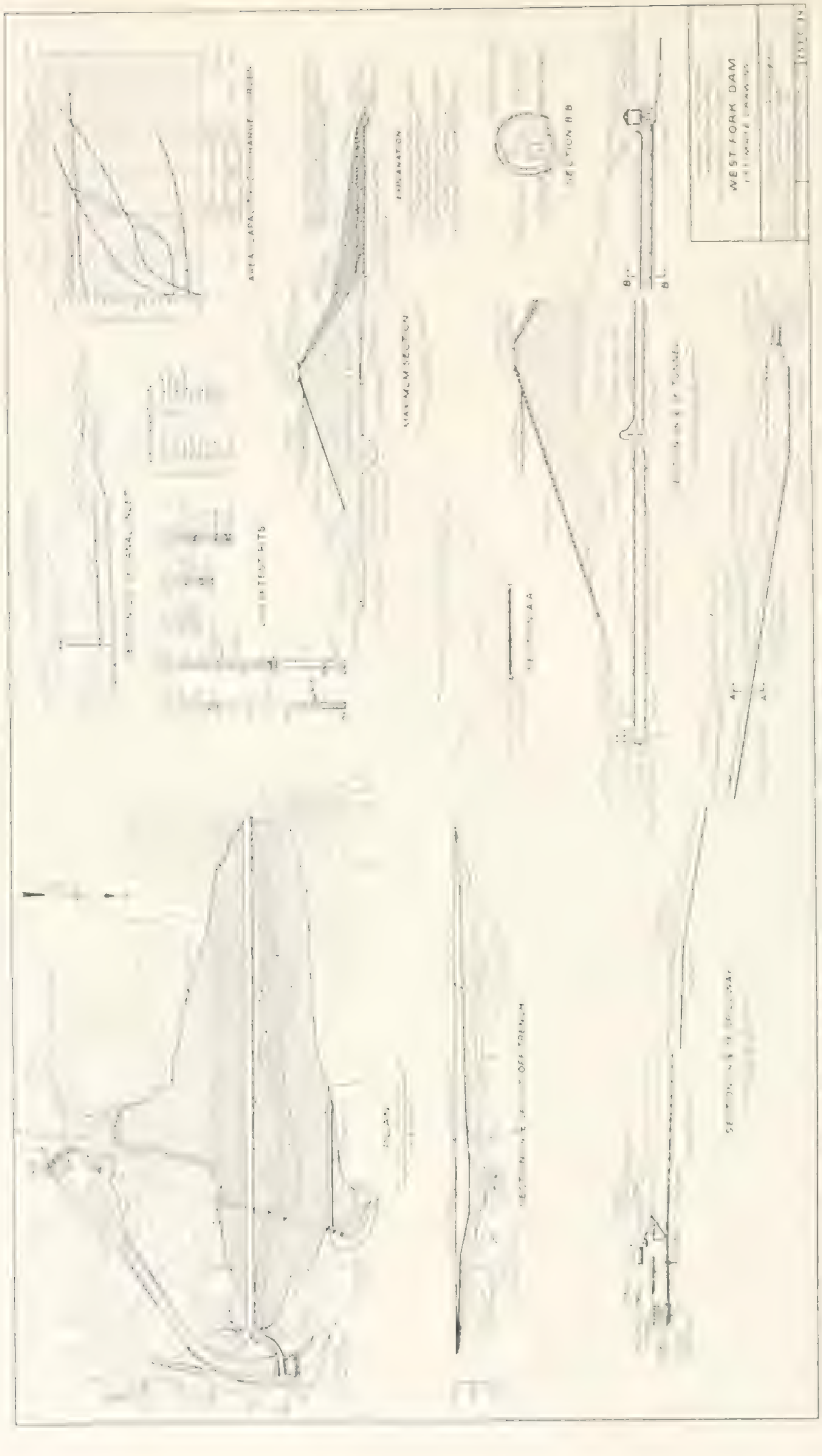


Figure 108

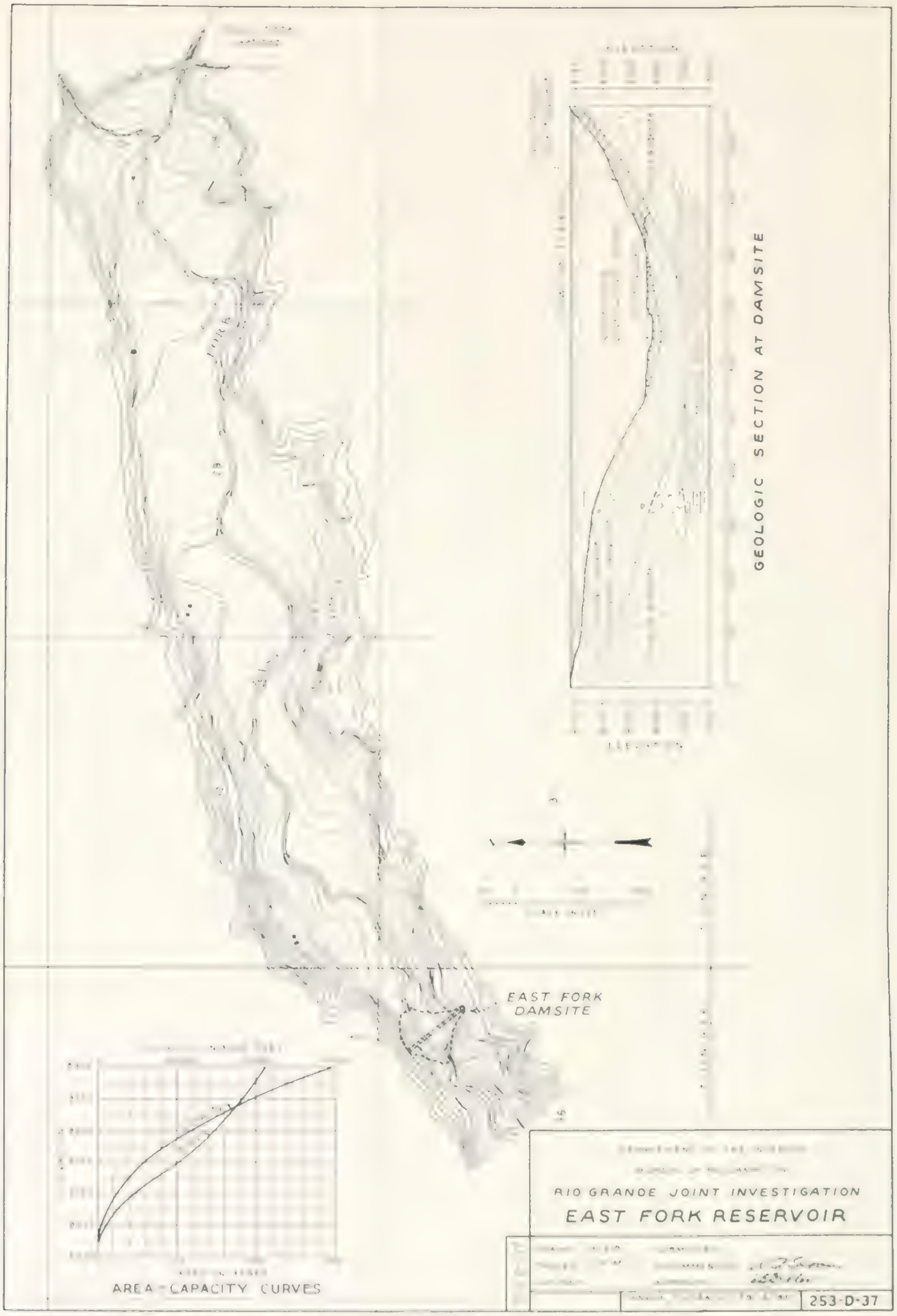
TABLE 3.—*Department of the Interior, Bureau of Reclamation, Rio Grande joint investigations, Colorado, West Fork San Juan Dam, preliminary estimate, Jan. 30, 1937*

[Earth embankment: Top of dam, elevation 7,888; normal water surface, elevation 7,880; [illegible]]

[Storage capacity, 70,000 acre-feet; spillway capacity, 13,000 second-feet; diversion capacity, 4,000 second-feet; required outlet capacity, 300 second-feet]

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
RIVER WORK								
Diversion and unwatering foundation	(1)		(1)	$3,000			(1)	$3,000.00
EARTHWORK								
Excavation, common:								
Stripping, dam foundation	[illegible]	Cubic yard	$0.30	[illegible]			$0.30	15,900.00
Stripping, borrow pits	145,000	Cubic yard	.30	43,500			.30	43,500.00
Toe drains and cut-off trenches	159,400	Cubic yard	.40	63,760			.40	[illegible]
Spillway	199,800	Cubic yard	.30	59,940			.30	[illegible]
Spillway and tunnel inlet and outlet	22,400	Cubic yard	.40	8,960			.40	8,960.00
Tunnel	8,300	Cubic yard	7.50	62,250			7.50	62,250.00
Roadway	1,800	Cubic yard	.75	1,350			.75	1,350.00
Borrow and transportation to dam	2,111,200	Cubic yard	.25	527,800			.25	527,800.00
Excavation, rock: Borrow and transportation to dam	218,000	Cubic yard	.75	163,500			.75	163,500.00
Embankment:								
Earth fill compacted	2,056,800	Cubic yard	.08	164,544			.08	164,544.00
Dumped rock on downstream slope	278,800	Cubic yard	.20	55,760			.20	55,760.00
Riprap rock on upstream slope	81,200	Cubic yard	.40	32,480			.40	32,480.00
Backfill about structures	24,200	Cubic yard	.50	12,100			.50	12,100.00
Gravel for roadway and spillway	5,440	Cubic yard	1.25	6,800			1.25	6,800.00
Oversized gravel and boulders downstream slope	92,900	Cubic yard	.10	9,290			.10	9,290.00
Spillway riprap	750	Cubic yard	.40	300			.40	300.00
GROUTING AND DRAINAGE								
Drain tile:								
12-inch diameter clay tile in gravel	800	Linear foot	.70	560	$0.45	360	1.15	920.00
8-inch diameter clay tile in gravel	5,000	Linear foot	.60	3,000	.30	1,500	.90	4,500.00
6-inch diameter clay tile in gravel	1,300	Linear foot	.50	650	.20	260	.70	910.00
Pressure grouting: Tunnel	5,000	Linear foot	1.00	5,000	.80	4,000	1.80	9,000.00
CONCRETE WORK								
Concrete:								
Parapets and curb walls	970	Cubic yard	18.00	17,460	4.00	3,880	22.00	21,340.00
Trash rack and transition	180	Cubic yard	14.75	2,655	4.00	720	18.75	3,375.00
Below operating floor of gate chamber	180	Cubic yard	12.50	2,250	3.60	648	16.10	2,898.00
Tunnel and gate chamber	1,950	Cubic yard	12.00	23,400	4.00	7,800	16.00	31,200.00
Spillway floor and cut-off walls	4,300	Cubic yard	9.00	38,700	4.00	17,200	13.00	55,900.00
Spillway walls	1,275	Cubic yard	11.25	14,344	4.00	5,100	15.25	19,444.00
Spillway counterforted walls	1,130	Cubic yard	14.00	15,820	4.00	4,520	18.00	20,340.00
Spillway piers and bridge	415	Cubic yard	12.50	5,187	3.60	1,494	16.10	6,681.00
Channel to valve house	215	Cubic yard	11.50	2,473	4.00	860	15.50	3,333.00
Valve house substructure	100	Cubic yard	12.50	1,250	3.60	360	16.10	1,610.00
Valve house superstructure	30	Cubic yard	22.00	660	4.00	120	26.00	780.00
Canal outlet	350	Cubic yard	16.50	5,775	4.00	1,400	20.50	7,175.00
Special finishing of concrete surfaces	2,000	Square yard	.60	1,200			.60	1,200.00
METALWORK								
Metal:								
Trash rack	32,000	Pound	.02	640	.08	2,560	.10	[illegible]
Reinforcement steel	1,065,000	Pound	.02	21,300	.03	31,950	.05	[illegible]
Steel liner plate	500,000	Pound			.05	25,000	.05	25,000.00
57-inch ring-follower gate and control mechanism	43,600	Pound	.04	1,744	.24	10,464	.28	[illegible]
48-inch needle valve and control mechanism	37,600	Pound	.03	1,128	.22	8,272	.25	9,400.00
8-ton hoist	28,000	Pound	.02	560	.19	5,320	.21	[illegible]
Gas-electric generator set and equipment	(1)		(1)	200	(1)	800	(1)	[illegible]
57-inch inside diameter outlet pipes	212,000	Pound	.025	5,300	.07	14,840	.095	[illegible]
20- by 17-foot radial gates and operating mechanism	109,000	Pound	.03	3,270	.09	9,810	.12	13,080.00
44- by 55-foot face gates and operating mechanism	8,300	Pound	.02	166	.08	664	.10	830.00
Miscellaneous metalwork	20,000	Pound	.10	2,000	.10	2,000	.20	4,000.00
MISCELLANEOUS ITEMS								
Items:								
Control house except concrete	(1)		(1)	300	(1)	1,200	(1)	1,500.00
Transporting freight except cement for Government from South Fork, Colorado, to the dam site (29.5 miles)	1,040	Ton	3.25	3,380				3,380.00
Highway construction	3	Mile	15,000.00	45,000				45,000.00
Telephone and utility lines	3	Mile	300.00	900	200.00	600	500.00	1,500.00
Right-of-way	1,100	Acre			37.00	40,700	37.00	40,700.00
Subtotals				1,457,506		[illegible]		1,662,308.00
Contingencies: 15 percent								249,346.00
Total estimated field cost								1,911,654.00
Investigations and surveys	(1)						(1)	5,000.00
Engineering and inspection, 5 percent								95,583.00
Superintendence and accounts, 1 percent								19,117.00
General expense, 2 percent								[illegible]
Total estimated cost								2,069,588.00
Cost per acre-foot of storage								29.57

[1] Lump sum.


GEOLOGIC SECTION AT DAMSITE
EAST FORK DAMSITE
AREA-CAPACITY CURVES
RIO GRANDE JOINT INVESTIGATION
EAST FORK RESERVOIR
253-D-37

East Fork Reservoir

The East Fork dam site is in section 36, T. 37 N., R. 1 E., of Mineral County, Colo., and approximately 6 miles above the junction of the East and West Forks of the San Juan River.

A storage capacity of 35,000 acre-feet capacity is required for regulation of East Fork waters for diversion to Rio Grande.

Summary of estimate data

Storage capacity	35,000 acre-feet
Spillway capacity	10,000 second-feet
Outlet capacity at low water	300 second-feet.
Elevation—top of dam	8,167.
Maximum and normal reservoir water-surface elevation	8,160.
Reservoir area at elevation 8,160	570 acres.
Height of dam	150 feet.
Total estimated cost—dam and reservoir	$1,449,000.
Preliminary estimate	Table 4
Reservoir topography and geologic cross-section	Figure 109.
General plan and sections	Figure 110.

Geological summary.—The basin is a normal erosional valley eroded into a somewhat unusual and interesting bedrock complex. In brief, the foundation rock is believed to be irregularly eroded black shale (Mancos) over which a series of volcanic andesite flows (Conejos) was erupted. Recent erosion has reached shale in the basin while immediately below the axis the river is still flowing on andesite. The bottom flats in the reservoir are heavily mantled with stratified gravels, while terrace remnants of similar loose, permeable gravels line the sides. Irregular wash, slide, and glacial deposits are also to be found. The water table is tributary to the stream and no reservoir seepage is to be expected other than some downstream movement through the detrital deposits.

The dam site occupies the only economical narrows commanding this basin. The old shale surface, on which the andesites were extruded, dips downstream in this area. This contact zone comes to the surface in the vicinity of the dam site, so that the immediate rock foundation on the axis is probably shale or sandstone, although andesite may be encountered. The only bedrock that possibly can be utilized during construction, provided the detrital foundation materials are not excavated, is the andesite in the right abutment. This rock is more in the nature of a flow breccia, an angularly broken and fractured andesite that is somewhat recemented. The character of the contact materials is not known, as no exposures were found.

The site must depend almost entirely upon the control and use of the various overburden materials. On the right abutment a talus deposit of unknown character and possibly 100 feet deep overlies andesite breccia. This debris may prove to be quite permeable depending upon the amount of interstitial silts. No pits have been dug. The foundation gravels may extend for some distance under the right talus and possibly also under the left moraine. These loose permeable gravels are of unknown depth. The left abutment is composed entirely of a glacial moraine of undetermined quality but surface exposure indicates an unusually thick assemblage of semiangular boulders, gravel, sand and silt, the whole appearing unusually compact. It is believed that this moraine is lying on and against landslide rubble.

Dam.—Since the dam foundation consists of glacial moraine material, a compacted embankment type was selected. It is estimated there is sufficient embankment borrow material within 1 mile of the site. There appear to be ample sand and gravel deposits along the river within one-half mile upstream for the required amount of concrete. No tests have yet been made to determine suitability of these materials for construction purposes. Rock for the downstream toe is available in nearby talus slopes.

The dam is 1,140 feet in length along the crest and attains a maximum height of 140 feet above river bed. A deep cut-off trench extends the entire length of the dam, the excavation from which can be used in the downstream portion of the embankment. Sufficient rock is to be placed against the downstream side of the embankment to make it stable. The entire area under the dam will require stripping of vegetation.

The spillway, located in the left abutment, contains three 17 feet long by 16 feet high automatic radial gates constructed to withstand ice pressure. The gate structure, spillway channel, and stilling basin, are of reinforced concrete, with counterforted and cantilever wall construction. With water at elevation 8,160, the discharge capacity of the spillway is 10,000 second-feet. The drainage area is 60 square miles.

A 12-foot diameter horseshoe tunnel with steel liner plates and concrete lining will be used for diversion of stream flow and later as outlet tunnel. The inlet and trash rack is placed a short distance above the reservoir floor to provide a depth for storage of materials brought in by the stream and for protection of fish. A single 57-inch emergency ring follower gate is placed in a chamber in the tunnel under the axis of the dam. From the gate chamber a 57-inch steel pipe leads downstream in the tunnel to a single 48-inch needle valve. The needle valve, which is located in a valve house at the downstream end of the tunnel, discharges into the spillway stilling basin. The gate chamber and valve house are to be equipped with the necessary pumps, piping, cranes, etc., required for operation. It is planned to install a gas-engine-driven generator to supply energy to operate gates and furnish lights.

It will require approximately 2½ years to construct the dam and appurtenant works. No electric power is

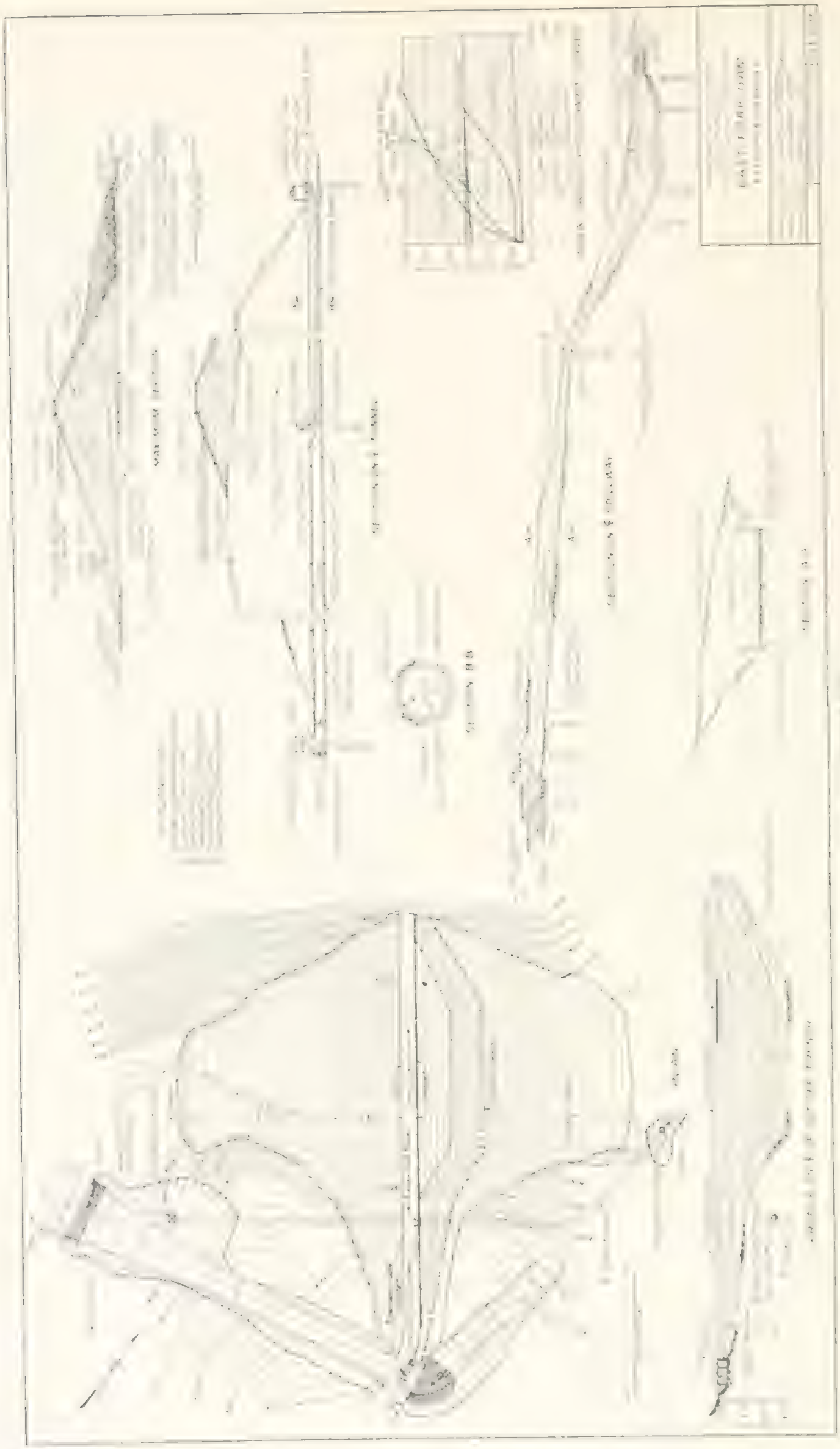


TABLE 4.—*Department of the Interior, Bureau of Reclamation, Rio Grande joint investigations, Colorado East Fork San Juan Dam, preliminary estimate, Jan. 30, 1937*

[Earth embankment: Top of dam, elevation 8,167; normal water surface elevation, 8,160; maximum water surface elevation, 8,160; maximum height of dam, 150 feet; drawing 253-D-36.]

[Storage capacity, 35,000 acre feet; spillway capacity, 10,000 second-feet; diversion capacity, 2,000 second-feet: required outlet capacity, 300 second-feet]

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
RIVER WORK								
Diversion, and unwatering foundation	(1)			$3,000				$3,000
EARTHWORK								
Excavation, common:								
Stripping, dam foundation	49,000	Cubic yard	$0.30	14,700			$0.30	14,700
Stripping, borrow pits	67,000	Cubic yard	.30	20,100			.30	20,100
Tunnel	8,700	Cubic yard	7.50	65,250			7.50	65,250
Toe drains and cut-off trenches	54,300	Cubic yard	.40	21,720			.40	21,720
Spillway, and tunnel inlet and outlet	114,000	Cubic yard	.40	45,600			.40	45,600
Spillway	87,100	Cubic yard	.30	26,130			.30	26,130
Borrow, and transportation to dam	1,181,000	Cubic yard	.25	295,250			.25	295,250
Excavation, rock: Borrow, and transportation to dam	161,200	Cubic yard	.75	120,900			.75	120,900
Embankment:								
Earth fill compacted	1,182,000	Cubic yard	.10	118,200			.10	118,200
Dumped rock on downstream slope	184,500	Cubic yard	.20	36,900			.20	36,900
Riprap rock on upstream slope and spillway	30,500	Cubic yard	.40	12,200			.40	12,200
Backfill about structures	6,000	Cubic yard	.50	3,000			.50	3,000
Gravel for roadway and under spillway	2,700	Cubic yard	1.25	3,375			1.25	3,375
Oversized boulders and gravel on downstream slope	61,500	Cubic yard	.10	6,150			.10	6,150
GROUTING AND DRAINAGE								
Pressure grouting: Tunnel	5,000	Cubic foot	1.00	5,000	$1.00	$5,000	2.00	10,000
Drain tile:								
12-inch diameter clay tile in gravel	600	Linear feet	.70	420	.45	270	1.15	690
8-inch diameter clay tile in gravel	2,500	Linear feet	.60	1,500	.30	750	.90	2,250
6-inch diameter clay tile in gravel	1,000	Linear feet	.50	500	.20	200	.70	700
4-inch diameter clay tile in gravel	200	Linear feet	.30	60	.20	40	.50	100
CONCRETE WORK								
Concrete:								
Tunnel cut-off collars	100	Cubic yard	9.00	900	4.00	400	13.00	1,300
Spillway floor and cut-off walls	3,500	Cubic yard	9.00	31,500	4.00	14,000	13.00	45,500
Spillway walls	330	Cubic yard	11.25	3,712	4.00	1,320	15.25	5,032
Spillway counterforted walls	760	Cubic yard	14.00	10,640	4.00	3,040	18.00	13,680
Spillway piers and bridge	320	Cubic yard	12.50	4,000	3.60	1,152	16.10	5,152
Channel to valve house	100	Cubic yard	11.50	1,150	4.00	400	15.50	1,550
Parapet and curb walls	400	Cubic yard	18.00	7,200	4.00	1,600	22.00	8,800
Trash rack and transition	100	Cubic yard	14.75	1,475	4.00	400	18.75	1,875
Below operating floor of gate chamber	180	Cubic yard	12.50	2,250	3.60	648	16.10	2,898
Tunnel and gate chamber	1,900	Cubic yard	12.00	22,800	4.00	7,600	16.00	30,400
Needle-valve house substructure	100	Cubic yard	12.50	1,250	3.60	360	16.10	1,610
Needle-valve house superstructure	30	Cubic yard	22.00	660	4.00	120	26.00	780
Special concrete finishing	710	Square yard	.60	426			.60	426
METALWORK								
Metal:								
Trash rack	17,300	Pound	.02	346	.08	1,384	.10	1,730
Reinforcement steel	649,500	Pound	.02	12,990	.03	19,485	.05	32,475
Steel liner plates	517,000	Pound			.05	25,850	.05	25,850
27-inch inside diameter outlet pipes	210,000	Pound	.025	5,250	.07	14,700	.095	19,950
27-inch ring-follower gate and control mechanism	43,600	Pound	.04	1,744	.24	10,464	.28	12,208
18-inch needle valve and control mechanism	37,600	Pound	.03	1,128	.22	8,272	.25	9,400
Gate hoist	28,000	Pound	.02	560	.19	5,320	.21	5,880
Gas-electric generator set and equipment			(1)	200	(1)	800	(1)	1,000
Miscellaneous metalwork	26,100	Pound	.10	2,610	.10	2,610	.20	5,220
17- by 16-foot radial gates and operating mechanism	85,000	Pound	.03	2,550	.09	7,650	.12	10,200
MISCELLANEOUS ITEMS								
Items:								
Control house, except concrete			(1)	300	(1)	1,200	(1)	1,500
Transporting freight except cement for Government from South Fork, Colo., to the dam site (43 miles).	791	Ton	4.75	3,757				3,757
Highway construction	5	Mile	20,000.00	100,000			20,000	100,000
Telephone and utility lines	2	Mile	300.00	600	200	400	500	1,000
Clearing reservoir	50	Acre	25.00	1,250			25.00	1,250
Right-of-way	250	Acre			25.00	6,250	25.00	6,250
Subtotals				1,021,203		141,685		1,162,888
Contingencies, 15 percent								174,433
Total estimated field cost								1,337,321
Investigations and surveys	(1)						(1)	5,000
Engineering and inspection, 5 percent								66,866
Superintendence and accounts, 1 percent								13,373
General expense, 2 percent								26,746
Total estimated cost								1,449,306
Cost per acre-foot of storage								41.41

[1] Lump sum.


RIO GRANDE JOINT INVESTIGATION
BLANCO RESERVOIR
253-D-39
GEOLOGIC SECTION AT DAMSITE
AREA-CAPACITY CURVES

available in this locality. The nearest railroad shipping point is South Fork, Colo., a distance of 38 miles, of which 33 miles is U. S. Highway No. 160, over Wolf Creek Summit, and 5 miles will be new road of difficult construction. About 50 acres of the reservoir site will require clearing.

Blanco Reservoir

The Blanco dam site is located on the Rio Blanco, a tributary of the San Juan River, in sections 1 and 12, T. 34 N., R. 1 E., of Archuleta County, Colo., about 13 miles southeast of Pagosa Springs. A storage capacity of 15,000 acre-feet is required at this site to detain flood waters in excess of the capacity of the San Juan-Chama Canal.

Summary of data:

Storage capacity	15,000 acre-feet.
Spillway capacity	12,000 second-feet.
Outlet capacity at low water	500 second-feet.
Elevation—top of dam	8,007.
Normal and maximum water surface elevation.	8,000.
Height of dam above stream level	102 feet.
Total estimated cost—dam and reservoir.	$1,060,494.
Preliminary estimate	Table 5.
Reservoir topography and geologic sections.	Figure 111.
General plan and sections of dam	Figure 112.

The reservoir area at elevation 8,007 is 325 acres, of which 150 acres are privately owned lands and approximately 100 acres will require clearing. The area of the watershed is 69 square miles.

Geological summary.—The Blanco Basin is a normal erosional feature cut into black shale of the Mancos series which is found in the bottom beneath a thick deposit of river gravels. This shale is substantially horizontal but may dip slightly upstream. Overlying this shale but everywhere well above the flow line, is found a capping of Conejos andesite. The contact between the two is very irregular, the andesite having submerged the hills and valleys of the eroded shale topography. Intrusive igneous dikes are apparently common in the shale, and examples were encountered by the churn drill at the dam site. The entire reservoir floor is heavily mantled with porous river gravels, while the basin sides are covered with glacial terrace gravel and moraine, as well as extensive, erratic wash, and slump debris. Consideration of the bedrock character, together with observation of springs and seeps, suggests that the ground water is tributary to the stream and that no reservoir loss can occur, except as seepage downstream through the various detrital materials.

The dam site must depend entirely upon similar overburdens both for support and adequate impermeability. Two alternative axes were explored at the lower narrows before selection of the final proposed dam site. Three pits were dug on the rejected axis while three pits and two churn drill holes were completed at the present axis. The eventual bedrock is the Mancos formation of the reservoir; a black, compact shale that in itself should be sufficiently impervious and stable for earth-dam construction. A study of the overburdens shows that several types of deposits will be encountered. The immediate foundation, in the river, is a recent stratified gravel probably resting at no great depth on glacial moraine. The latter debris forms the right abutment, where pits indicate a fairly compact assemblage of boulders, gravel, sand, and clay that appears quite stable and relatively impervious. On the other hand, the left abutment is composed largely of glacial terrace outwash; a stratified deposit that has alternating gravel, silt, and clay layers. Erratic moraine debris is also found as evidenced by several extremely large boulders 20 to 30 feet in diameter. Layers of the outwash will prove to be very porous and although these can be expected to have a lensed character, some horizons may extend over long distances, long enough to pass entirely beneath the dam. In this regard, the lensing will be more pronounced laterally, while channellike areas are more likely to extend up and down stream. The water table in this debris fluctuates widely, depending upon the amount of irrigation. With none, it is believed that it would be found close to the present river level. Two drill holes show the shale to be 118 feet beneath the surface in the river channel and 88 feet under the left abutment.

Dam.—Figure 112 shows the general plan and sections for the proposed dam. Excavation to bedrock was considered too costly and not necessary. The proposed dam is of the compacted embankment type with a deep cut-off trench, the material from which can be used in the downstream portion of the embankment. Sufficient rock is placed on the downstream slope to make the embankment stable. The crest of the dam is 2,300 feet in length and the maximum height at the river section is 102 feet. There appears to be sufficient embankment material adjacent to the site. Sand and gravel deposits are about one-half mile upstream but no pits have been dug nor analyses made to determine their extent or quality. The entire dam foundation will require stripping of vegetation.

A gate spillway with a maximum capacity of 12,000 second-feet will be constructed in glacial debris material on the right abutment. The gate structure provides the necessary freeboard without raising the dam. Three automatic radial gates, 18 feet long by 17 feet high, will be constructed to withstand ice pressure. The gate structure is of reinforced concrete with counterfort type side walls. A roadway over the dam and spillway may be extended to join the present road at the right abutment.

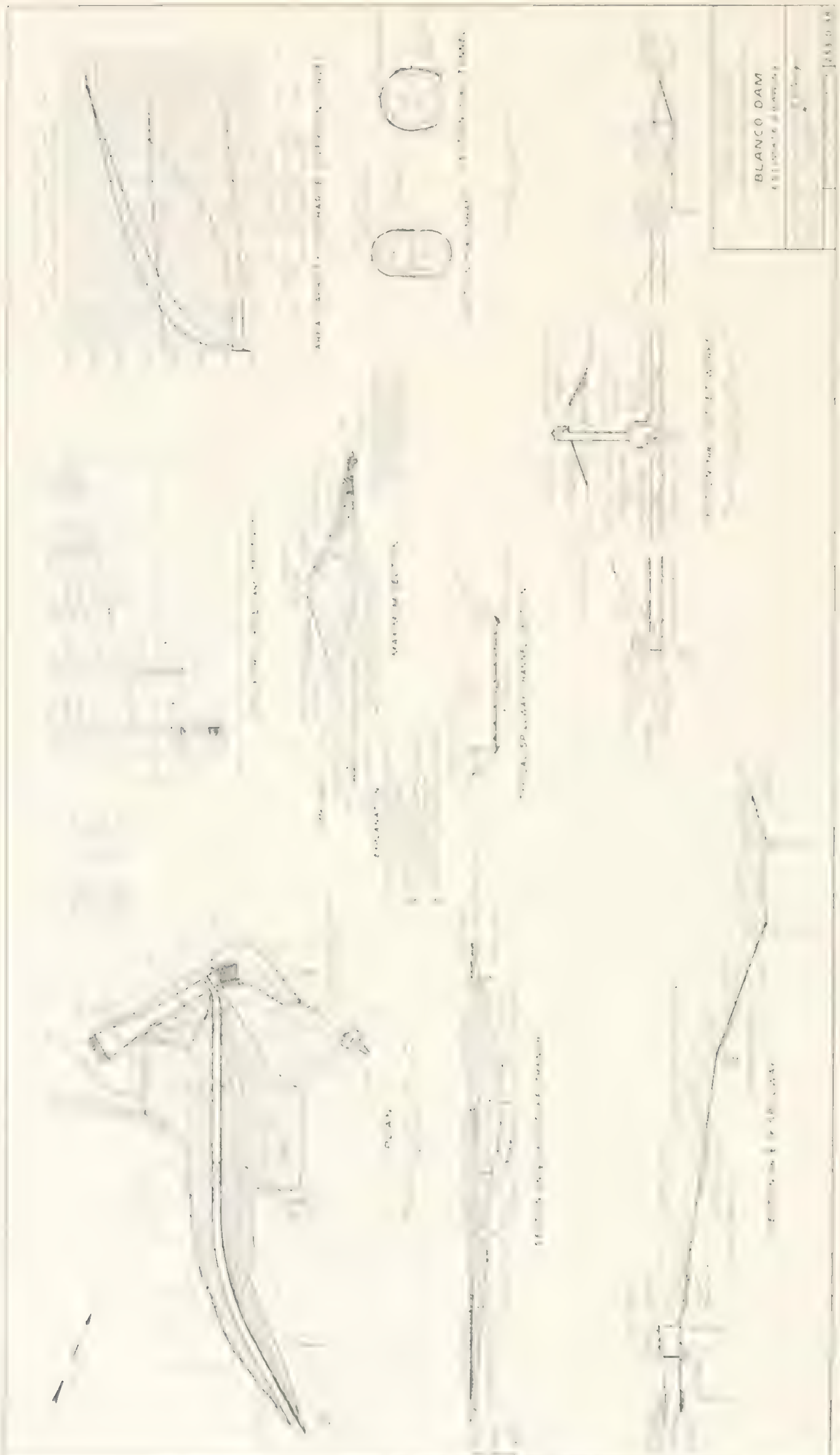


FIGURE 112

For diversion and outlet purposes, a 12-foot diameter horseshoe tunnel with steel liner plates and concrete lining is provided under the right abutment. The inlet and trash rack is placed above the floor of the reservoir to keep sand and gravel washed in by the river out of the outlet, and for protection of fish. The outlet works consist of one 66-inch needle valve and one 54-inch ring follower emergency gate located in a chamber in the tunnel under the axis of the dam. The needle valve discharges into the tunnel which, in

TABLE 5.—*Blanco Dam, preliminary estimate, Jan. 30, 1937*

Earth embankment: top of dam, elevation 8,007; normal water surface, elevation 8,000; spillway crest, elevation 7,983; maximum height of dam, 110 feet; drawing no. 253-D-38

[Storage capacity, 15,000 acre-feet; spillway capacity, 12,000 second-feet; diversion capacity, 3,000 second-feet; required outlet capacity, 500 second-feet]

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
RIVER WORK								
Diversion and unwatering foundations	(1)		(1)	$4,000			(1)	$4,000.00
EARTHWORK								
Excavation common:								
Stripping dam foundation	41,000	Cubic yard	$0.30	12,300			$0.30	12,300.00
Stripping borrow pits	33,000	Cubic yard	.30	9,900			.30	9,900.00
Toe drains, and cut-off trenches	135,000	Cubic yard	.40	54,000			.40	54,000.00
Spillway, tunnel inlet and outlet	115,000	Cubic yard	.40	46,000			.40	46,000.00
Tunnel shaft and gate chamber	8,600	Cubic yard	7.50	64,500			7.50	64,500.00
Borrow and transportation to dam	738,500	Cubic yard	.25	184,625			.25	184,625.00
Excavation rock: Borrow and transportation to dam	78,100	Cubic yard	.75	58,575			.75	58,575.00
Embankment:								
Earth fill compacted	887,500	Cubic yard	.10	88,750			.10	88,750.00
Dumped rock on downstream slope	70,500	Cubic yard	.20	14,100			.20	14,100.00
Riprap rock on upstream slope of dam and spillway [illegible]	35,000	Cubic yard	.40	14,000			.40	14,000.00
Backfill about structures	10,000	Cubic yard	.50	5,000			.50	5,000.00
Gravel for roadway and spillway	3,600	Cubic yard	1.25	4,500			1.25	4,500.00
Oversized gravel and boulders on downstream slope	23,500	Cubic yard	.10	2,350			.10	2,350.00
GROUTING AND DRAINAGE								
Drilling: Weep holes	300	Linear foot	1.00	300			1.00	300.00
Pressure grouting: Tunnel	4,500	Linear foot	1.00	4,500			1.00	4,500.00
Drain tile:								
12-inch diameter clay tile drain in gravel	700	Linear foot	.70	490	$0.45	315	1.15	805.00
8-inch diameter clay tile drain in gravel	2,300	Linear foot	.60	1,380	.30	690	.90	2,070.00
6-inch diameter clay tile drain in gravel	1,800	Linear foot	.50	900	.20	360	.70	1,260.00
CONCRETE WORK								
Concrete:								
Trashrack and transition	100	Cubic yard	14.75	1,475	4.60	460	19.35	1,935.00
Tunnel and shaft lining	1,900	Cubic yard	14.00	26,600	4.60	8,740	18.60	35,340.00
Gate chamber	375	Cubic yard	12.00	4,500	4.15	1,556	16.15	6,056.00
Spillway gate structure	1,200	Cubic yard	11.00	13,200	4.15	4,980	15.15	18,180.00
Spillway channel	3,700	Cubic yard	11.75	43,475	4.60	17,020	16.35	60,495.00
Parapets and curb walls	850	Cubic yard	18.00	15,300	4.60	3,910	22.60	19,210.00
Control house	25	Cubic yard	18.00	450	4.60	115	22.60	565.00
Special concrete finishing	825	Square yard	.60	495			.60	495.00
METAL WORK								
Metal:								
Tunnel and shaft liner plates	407,000	Pound			.05	20,350	.05	20,350.00
Trashrack	14,000	Pound	.02	280	.08	1,120	.10	1,400.00
Reinforcement bars	400,000	Pound	.02	8,000	.03	12,000	.05	20,000.00
1 79-inch ring follower gate and control mechanism	81,000	Pound	.04	3,240	.24	19,440	.28	22,680.00
1 66-inch needle valve and operating mechanism	66,000	Pound	.03	1,980	.22	14,520	.25	16,500.00
3 18 by 17-foot radial gates and operating mechanism	98,000	Pound	.03	2,940	.09	8,820	.12	11,760.00
Metal stairways and walkways	17,000	Pound	.03	510	.11	1,870	.14	2,380.00
Pipe handrailing	2,700	Pound	.03	81	.09	243	.12	324.00
Grout and drain pipe	2,500	Pound	.05	125	.07	175	.12	300.00
Miscellaneous metalwork	5,000	Pound	.10	500	.10	500	.20	1,000.00
Gas-electric generator set and equipment	(1)		(1)	200	(1)	800	(1)	1,000.00
Stem hoist	28,000	Pound	.02	560	.19	5,320	.21	5,880.00
MISCELLANEOUS ITEMS								
Items:								
Control house except concrete	(1)		(1)	200	(1)	800	(1)	1,000.00
Transporting freight except cement for Government from Lumberton, N. Mex., to the dam site (33.8 miles).	550	Ton	4.00	2,200			4.00	2,200.00
Highway construction	4	Mile	5,000.00	20,000			5,000.00	20,000.00
Telephone and utility lines	3	Mile	300.00	900	200.00	600	500.00	1,500.00
Clearing reservoir	100	Acre	25.00	2,500			25.00	2,500.00
Right-of-way	150	Acre			35.00	5,250	35.00	5,250.00
Subtotal				719,881		129,954		849,835.00
Contingencies, 15 percent								127,475.00
Total estimated field cost								977,310.00
Investigations and surveys	(1)						(1)	5,000.00
Engineering and inspection, 5 percent								48,865.00
Superintendence and accounts, 1 percent								9,773.00
General expense, 2 percent								19,546.00
Total estimated cost								1,060,494.00
Cost per acre-foot of storage								70.70

[1] Lump sum.


AREA-CAPACITY CURVES
GEOLOGICAL SECTION AT DAMSITE
ELEVATION
ELEVATION
DAMSITE
RIO GRANDE JOINT INVESTIGATION
NAVAJO RESERVOIR
253-D-41

Figure 115.

turn, empties into the spillway stilling basin. A control house on top of the dam is connected to the outlet chamber by means of a vertical shaft containing a spiral stairway. The outlet chamber is equipped with the necessary pumps, piping, cranes, etc., required for the operation of the gate and needle valve. It is planned to install a gasoline-electric generator set in the control house for the operation of the outlet works, spillway gates, and to provide lighting.

It will require approximately 2 years to construct the dam and appurtenant works.

No electric power is available locally for construction purposes. The nearest railroad shipping point is Lumberton, N. Mex. a distance of 33.8 miles over a dry-weather road (now being graveled in part) on the narrow-gage Denver & Rio Grande Western Railroad Co. line from Alamosa to Durango.

Navajo Reservoir

The Navajo dam site is located in section 13, T. 33 N., R. 2 E., N. M. P. M., of Archuleta County, about 20 miles southeast of Pagosa Springs.

The storage requirement at this site is 50,000 acre-feet to regulate the stream to the capacity of the San Juan-Chama Canal.

Summary of estimate data:

Storage capacity	50,000 acre-feet.
Spillway capacity	10,000 second-feet.
Outlet capacity at low levels	300 second-feet.
Elevation—top of dam	8,300.
Normal and maximum water-surface elevation.	8,293.
Height of dam above stream	120 feet.
Estimated cost—dam and reservoir	$1,515,000.
Topography of reservoir and geologic sections.	Figure 113.
General plan and sections	Figure 114.
Preliminary estimate	Table 6.

The reservoir at elevation 8,293 covers 1,075 acres of privately owned lands. No clearing is required.

Geological summary.—The reservoir basin is a normal erosional valley cut by both water and ice action into a foundation rock of Mancos shale, a dark-gray siltstone containing some brown sandstone lenses. Blanco Basin soft sandstones are probably also present. These are overlain by igneous andesite flows and flow breccias (Conejos formation) the lower contact of which is quite irregular. Most of this andesite is well above the flow line in the lower half of the basin but is to be found exposed in the bottom, to the north. All of the area is heavily mantled with various overburden deposits. The floor is covered with deep, porous river gravels, while the sides have irregular deposits of wash, slump and glacial terrace deposits. In view of the foundation shale, together with normal spring occurrences, the water table is undoubtedly tributary to the stream; so that no reservoir seepage is to be expected except as underflow downstream through the various detrital deposits.

No bedrock will be encountered during construction at the dam site, where the proposed dam must utilize overburden foundation and abutments. The eventual bedrock is in all probability Mancos shale. No drilling was done and depths to this rock are unknown, but three test pits and one drift were completed to give some indications of the overburden character. The shale in all probability has been intruded by igneous dikes and sills, which were accompanied by alteration and mineralizing solutions. Much of this alteration material from both the shale and overlying andesite is to be found in the slump material forming the abutments. Both abutments are of similar slump origin. The debris is composed of angular shale rock and rock fragments, embedded for the most part in a silty clay. Pits indicated a remarkably tight and impervious deposit, as compact perhaps as natural overburden materials can become. Both sides are of similar land slump material which in slow transit down the slopes has picked up and incorporated some glacial debris. Such slumping should be expected in this area, where the shale emerges from under the andesite to form soft, unresistant valley walls. It is believed that the material is now quite stable except, perhaps, high up on the sides and well above the flow line. The immediate river channel is covered with a veneer of recent river gravels (10–50 feet).

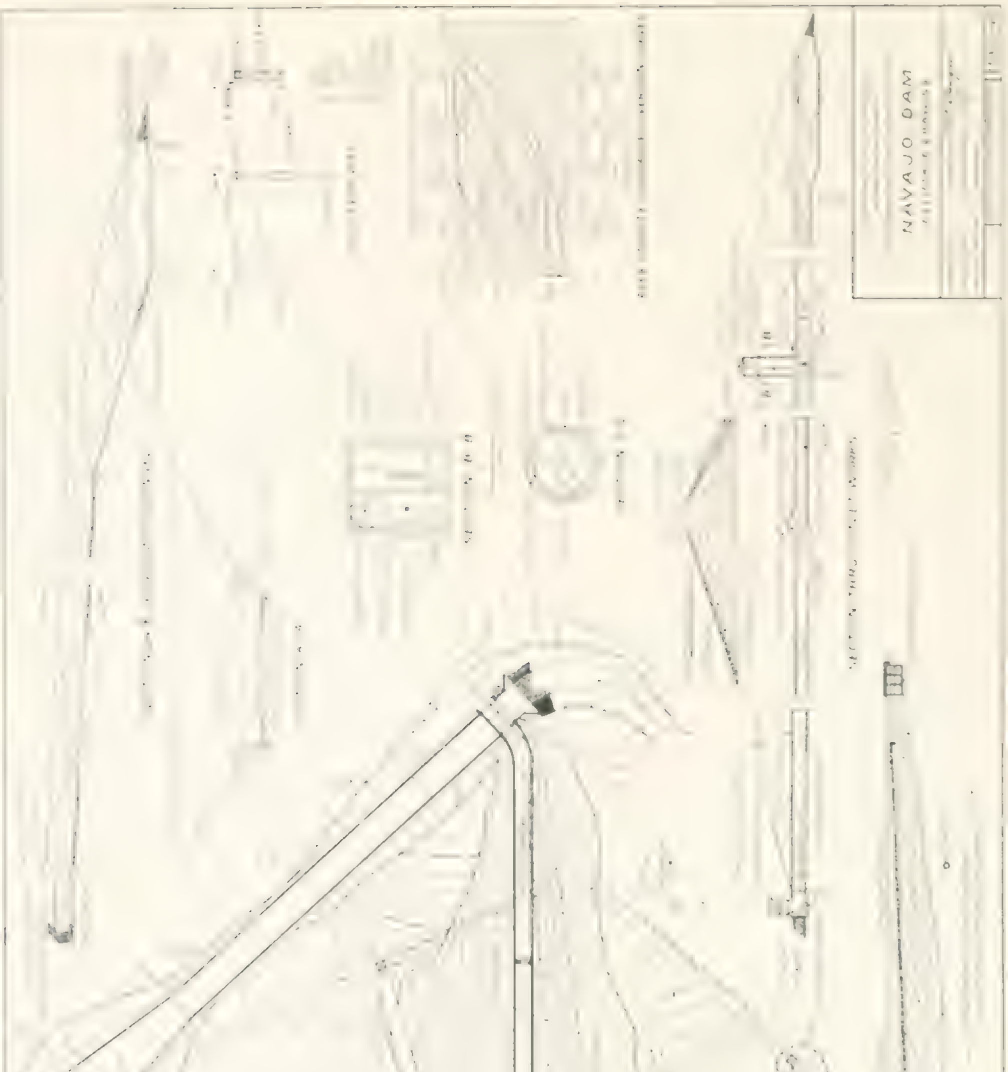
Dam.—The general plan and sections for the proposed dam are shown in figure 114. No information is available as to the depth to bedrock. However, it is considered at too great a depth for a cut-off to rock. The proposed dam is of the compacted embankment type with a deep cut-off trench. Sufficient rock is placed on the downstream slope to make the embankment stable.

The crest of the dam is 1,950 feet in length and the maximum height, at the river section, is 120 feet.

Sufficient quantities of embankment borrow material are thought to be available adjacent to the site. Sand and gravel deposits occur about one-half of a mile upstream but have been neither prospected nor analyzed.

The entire dam foundation will require stripping of vegetation. Excavation from the cut-off trench can be used to construct the downstream portion of the embankment.

The spillway at the right end of the dam will be a radial gate structure to obtain the required capacity and to provide the necessary free-board without raising the dam. From the test pit records the spillway will be in slide material, as test pits show bedrock will not be available at reasonable depth. Three 17-foot long


NAVAJO DAM

ity 16-foot high radial gates constructed to withstand the pressure are provided. The gate structure is of counterfort and cantilever type wall construction. A roadway is provided to connect with the existing road along the right abutment. The drainage area is 58 square miles.

For diversion and outlet purposes a 12-foot diameter horseshoe tunnel with steel liner plates and concrete lining is provided under the right abutment. The inlet of the trash rack is placed above the floor of the reservoir to keep sand and gravel out of the outlet and for fish protection.

[illegible]

[illegible]

Item	[illegible]		[illegible]		[illegible]		[illegible]	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]								
[illegible]	[illegible]	[illegible]		$[illegible]				$[illegible]
[illegible]								
[illegible]								
[illegible]	[illegible]	[illegible]	$0.[illegible]	[illegible]			$0.[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	.30	[illegible]			.30	[illegible]
[illegible]	[illegible]	[illegible]	.40	39,000			.40	39,000
[illegible]	[illegible]	[illegible]	.40	[illegible]			.40	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			.25	311,650
[illegible]	[illegible]	[illegible]	7.50	[illegible]			7.50	75,000
[illegible]	[illegible]	[illegible]	.75	126,750			.75	126,750
[illegible]								
[illegible]	[illegible]	Cubic yard..	.10	132,450			.10	132,450
[illegible]	[illegible]	[illegible]	[illegible]	36,740			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	.40	17,240			.40	[illegible]
[illegible]	6,100	Cubic yard...	.50	3,050			[illegible]	[illegible]
[illegible]	4,650	Cubic yard...	1.25	[illegible]			[illegible]	[illegible]
[illegible]	1,200	[illegible]	[illegible]	[illegible]			.60	[illegible]
[illegible]								
[illegible]	330	[illegible]	1.00	[illegible]			[illegible]	[illegible]
[illegible]	5,000	Cubic yard....	[illegible]	[illegible]	$[illegible]	$[illegible]	[illegible]	9,000
[illegible]								
[illegible]	1,600	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,840
[illegible]	1,750	Linear foot....	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,575
[illegible]	2,300	Linear foot....	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,610
CONCRETE WORK								
[illegible]								
[illegible]	[illegible]	Cubic yard..	17.50	14,000	4.60	[illegible]	22.10	[illegible]
[illegible]	90	Cubic yard..	14.25	[illegible]	[illegible]	414	18.85	[illegible]
Below operating floor of gate chamber..	300	Cubic yard..	[illegible]	[illegible]	4.15	1,245	[illegible]	4,695
[illegible]	[illegible]	Cubic yard..	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	50,680
[illegible]	4,750	Cubic yard..	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	Cubic yard..	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	Cubic yard..	17.50	[illegible]	[illegible]	[illegible]	[illegible]	553
[illegible]	[illegible]	Square yard	.60	[illegible]			[illegible]	[illegible]
[illegible]								
Metal:								
[illegible]	14,000	[illegible]	.02	[illegible]	[illegible]	[illegible]	[illegible]	1,400
[illegible]	600,000	Pound......	.02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	.05	[illegible]	.10	1,500	.15	2,250
[illegible]	[illegible]	Linear foot	.25	11	.40	[illegible]	.65	[illegible]
[illegible]	[illegible]	[illegible]	.03	2,550	.09	7,650	.12	10,200
[illegible]	[illegible]	[illegible]	.10	270	.10	[illegible]	.20	[illegible]
[illegible]	[illegible]	[illegible]	.04	3,240	[illegible]	[illegible]	[illegible]	[illegible]
66-inch needle valve and control mechanism........	[illegible]	[illegible]	.03	[illegible]	.22	[illegible]	.25	16,500
[illegible]	[illegible]	[illegible]	.02	[illegible]	.19	6,650	.21	7,350
[illegible]	(1)	[illegible]	[illegible]	200	[illegible]	800	[illegible]	1,000
[illegible]	5,000	Pound.....	.10	500	.10	[illegible]	.20	1,000
[illegible]	1,600	Pound......	.05	80	.07	112	.12	[illegible]
[illegible]	573,000	Pound......	[illegible]	[illegible]	[illegible]	[illegible]	.05	[illegible]
[illegible]	[illegible]	Pound......	.025	[illegible]	[illegible]	[illegible]	.095	10,260
MISCELLANEOUS ITEMS								
[illegible]								
[illegible]			(1)	200	(1)	[illegible]		1,000
[illegible] cement for Government from [illegible]	[illegible]	Ton .	2.50	1,700			[illegible]	1,700
[illegible]	[illegible]	Mile	[illegible]	5,000			[illegible]	5,000
Right-of-way........	1,075	[illegible]			[illegible]	[illegible]	[illegible]	53,750
Subtotal..............				1,006,174		[illegible]		1,215,893
[illegible]								182,384
Total estimated field cost..............								1,398,277
[illegible]								5,000
[illegible]								69,913
[illegible]								13,982
[illegible]								[illegible]
[illegible]								[illegible]
[illegible]								30.30

[1] Lump sum.

A gate chamber containing a single 79-inch ring follower emergency gate is placed in the tunnel at the axis of the dam. A 79-inch steel pipe leads downstream in the tunnel to a single 66-inch needle valve. The needle valve discharges into the tunnel, which in turn discharges into the stilling basin. A spiral stairway connects the control house on the surface with the needle valve chamber. The valve chamber contains one 66-inch needle valve with the necessary pumps, piping, cranes, etc., required for operation. It is planned to install a gas-electric set in the control house to supply energy for the operation of the valves and spillway gates and to provide lighting.

Construction.—It will require approximately 2½ years to complete this dam and appurtenant works. There is no local power available for construction purposes. The nearest railroad shipping point is Chama, N. Mex., on the narrow gage line from Alamosa to Durango, a distance of 20.7 miles over a dry weather road.

Boulder Lake Reservoir

Boulder Lake dam site is located about five miles south of Hillcrest, N. Mex., in the Jicarilla Apache Indian Reservation. The reservoir site is entirely on Government land under the supervision of the United States Indian Service.

This is an alternative site for Stinking Lake Reservoir. It has been adopted temporarily as a terminal reservoir for plan A of the San Juan-Chama Canal in this report because of its cheaper first cost, although further studies may show the desirability of using Stinking Lake Reservoir. A storage capacity of 290,000 acre-feet is required for regulation of waters brought in by the San Juan-Chama Canal to fit irrigation demands in the event sufficient reregulation is not secured at El Vado and Elephant Butte Reservoirs.

Summary of estimate data

Storage capacity	290,000 acre-feet.
Spillway capacity	Emergency only.
Outlet capacity	2,000 second-feet.
Elevation top of dam	7,313
Maximum reservoir water-surface elevation	7,305.
Maximum height of dam	158 feet.
Total estimated cost—dam and reservoir	$1,350,000.
Topography of reservoir and geologic sections	Figure 115.
General plan and sections	Figure 116.
Preliminary estimate	Table 7.

The reservoir area at elevation 7,305 is 4,750 acres, of which the present lake area is 250 acres. No clearing will be required on the reservoir area. There are no improvements.

Geological summary.—The regional and basin geological conditions have not been studied in detail. Inspection shows the valley to be the result of imposed or antecedent erosion on a bedrock complex of tilted sandstones and alternating shales. The drainage pattern has been inherited from that originally present on overlying, horizontal, tertiary sandstones, now entirely removed by erosion. The reservoir is underlain by compact shales of the Lewis Formation that overlie the same massive sandstones (Mesa Verde) which are found at the dam site. The rocks dip upstream, or 6° NW., strike N. 15° E. The compact impervious shale and the presence of the existing lake, suggest that the ground water is tributary to the stream and that no appreciable reservoir seepage is to be expected. The entire basin is heavily mantled with detrital silts so that bedrock is rarely observed. The sides of the valley also are covered with erratic talus or wash deposits depending upon the erosional form and the character of the bedrock.

In all probability, no unusual or serious problems would be encountered by an exploratory program. The bedrock is made up of a stratigraphic column of massive sandstone and alternating shale seams and beds of the Mesa Verde formation, which in this locality strike N. 15° E. and dip 6° NW. On account of this dip, the rocks become progressively more shaly both up and downstream from the proposed axis. The rock is somewhat fractured and jointed, so that some grouting may be required, but there is no evidence of any faulting. The rock on the abutments is similar, the strike extending undisturbed across the stream. The dip is a favorable feature, since water percolating along the bedding planes would be forced eventually to cross the beds to continue any movement downstream. The overburden condition of most importance to the dam site is found in the deep foundation silts, below the stream bed. The intermittent character of this stream has resulted in a partial back-filling of debris, which from surface exposures appears to be largely silt with occasional rock fragments. This silt may prove to be excessively deep (50–100 ft.), which, together with any tendency to become plastic on saturation, may allow considerable settlement and possible flowage.

There is no question as to the stability and imperviousness of the bedrock but some attention should be given to the fissle character of the interbedded shales and allowances made for possible dehydration and resultant surface disintegration.

Dam.—The compacted embankment type of dam was selected for this site due to excessive hauling distance for concrete materials and the close proximity of sufficient embankment materials. Although the greater portion of the site shows sandstone outcroppings, the central portion is overlain with silts and the underlying rock is at unknown depths. Location of sand and gravel deposits are uncertain but are thought to be

available about 10 miles from the site, for the limited amount of concrete necessary and are so assumed. Embankment materials can probably be found in nearby silt deposits. Figure 116 shows the general plan and sections of the proposed dam.

The dam is 825 feet long at the crest and attains a maximum height of 138 feet.

The typical embankment section as shown on the drawings consists of a 35-foot top width at elevation 7,313 carrying a graveled roadway and with typical

TABLE 7.—*Boulder Lake Dam, preliminary estimate Jan. 30, 1937*

[Earth embankment: Top of dam elevation 7,313; normal water surface, elevation 7,305; maximum water surface, elevation 7,305; maximum height of dam, 138 feet; drawing no 253-D-42]

[Storage capacity, 290,000 acre-feet; spillway capacity, emergency only; diversion capacity, none; required outlet capacity, 2,000 second-feet]

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
EXCAVATION								
Excavation, common:								
Stripping, dam foundation	35,500	Cubic yard	$0.30	$10,650			$0.30	$10,650
Stripping, borrow pits	144,000	Cubic yard	.30	43,200			.30	43,200
Toe drains and cut-off trenches	23,500	Cubic yard	.40	9,400			.40	9,400
Tunnel inlet and outlet	23,900	Cubic yard	.40	9,560			.40	9,560
Borrow, and transportation to dam	1,314,000	Cubic yard	.25	328,500			.25	328,500
Excavation, rock:								
Cut-off wall	110	Cubic yard	4.00	440			4.00	440
Tunnel inlet and outlet channel	2,500	Cubic yard	2.50	6,250			2.50	6,250
Borrow, and transportation to dam	128,800	Cubic yard	.75	96,600			.75	96,600
Outlet tunnel and shaft	10,100	Cubic yard	10.00	101,000			10.00	101,000
Embankment:								
Earth fill compacted	1,179,295	Cubic yard	.10	117,930			.10	117,930
Dumped rock on downstream slope	161,200	Cubic yard	.20	32,240			.20	32,240
Riprap rock on upstream slope	27,100	Cubic yard	.40	10,840			.40	10,840
Riprap rock in outlet channel	360	Cubic yard	.40	144			.40	144
Gravel for roadway	1,400	Cubic yard	2.50	3,500			2.50	3,500
Backfill about structures	100	Cubic yard	.50	50			.50	50
GROUTING AND DRAINAGE								
Drilling:								
Grout holes not over 25 feet deep	11,100	Linear feet	1.00	11,100			1.00	11,100
Weep holes	200	Linear feet	1.00	200			1.00	200
Pressure grouting: Tunnel, shaft, and cut-off wall	20,000	Cubic yards	1.00	20,000	$0.80	$16,000	1.80	36,000
Drain tile:								
12-inch diameter clay tile in gravel	500	Linear feet	.70	350	.45	225	1.15	575
8-inch diameter clay tile in gravel	1,200	Linear feet	.60	720	.30	360	.90	1,080
6-inch diameter clay tile in gravel	750	Linear feet	.50	375	.20	150	.70	525
4-inch split tile for spillway	600	Linear feet	.30	180	.20	120	.50	300
CONCRETE WORK								
Concrete:								
Cut-off wall not formed	80	Cubic yard	11.00	880	4.15	332	15.15	1,212
Cut-off wall formed	230	Cubic yard	12.50	2,875	4.60	1,058	17.10	3,933
Parapets and curb walls	320	Cubic yard	18.50	5,920	4.60	1,472	23.10	7,392
Trash rack, transition, and stilling basin	450	Cubic yard	15.75	7,087	4.60	2,070	20.35	9,157
Below operating floor of gate chamber	630	Cubic yard	13.00	8,190	4.15	2,614	17.15	10,804
Tunnel shaft and gate chamber	2,700	Cubic yard	15.00	40,500	4.15	11,205	19.15	51,705
Special finishing concrete surfaces	550	Square yard	.60	330			.60	330
Control house	20	Cubic yard	20.25	405	4.60	92	24.85	497
METALWORK								
Metal:								
Trash rack	50,000	Linear foot	.02	1,000	.08	4,000	.10	5,000
Reinforcement steel	168,000	Pound	.02	3,360	.03	5,040	.05	8,400
Spiral stairway	21,700	Pound	.05	1,085	.10	2,170	.15	3,250
Water stops	120	Linear foot	.25	30	.40	48	.65	75
Gate chamber stairway	1,200	Pound	.05	60	.10	120	.15	180
Pipe hand-railing	1,120	Pound	.10	112	.10	112	.20	224
2 [illegible]-inch ring-follower gates and control mechanism	164,000	Pound	.04	6,560	.24	39,360	.28	45,920
2 [illegible]-inch needle valves and control mechanism	140,000	Pound	.03	4,200	.22	30,800	.25	35,000
15-ton hoist	35,000	Pound	.02	700	.19	6,650	.21	7,350
Gas-electric generator set and equipment	(1)		(1)	200	(1)	800	(1)	1,000
Miscellaneous items	2,000	Pound	.10	200	.10	200	.20	400
Grout and drain pipe	3,700	Pound	.05	185	.07	259	.12	444
MISCELLANEOUS ITEMS								
Items:								
Control house except concrete	(1)		(1)	300	(1)	1,200	(1)	1,500
Transporting freight except cement for Government from Dulce, N. Mex., to dam site, 20 miles	304	Ton	2.20	669			2.20	669
Highway construction	3	Mile	10,000.00	30,000			10,000.00	30,000
Right-of-way	3,000	Acre			10.00	30,000	10.00	30,000
Emergency spillway in saddle				5,000			(1)	5,000
Subtotal				925,077		154,457		1,079,534
Contingencies, 15 percent								161,930
Total estimated field cost								1,241,464
Preliminary investigations and surveys								5,000
Engineering and inspection, 5 percent								62,073
Superintendence and accounts, 1 percent								12,415
General expense, 2 percent								24,829
Total estimated cost								1,345,781
Cost per acre-foot of storage								4.64

[1] Lump sum.


RIO GRANDE JOINT INVESTIGATION
BOULDER LAKE RESERVOIR
253-D-43
AREA CAPACITY CURVES

FIGURE 113

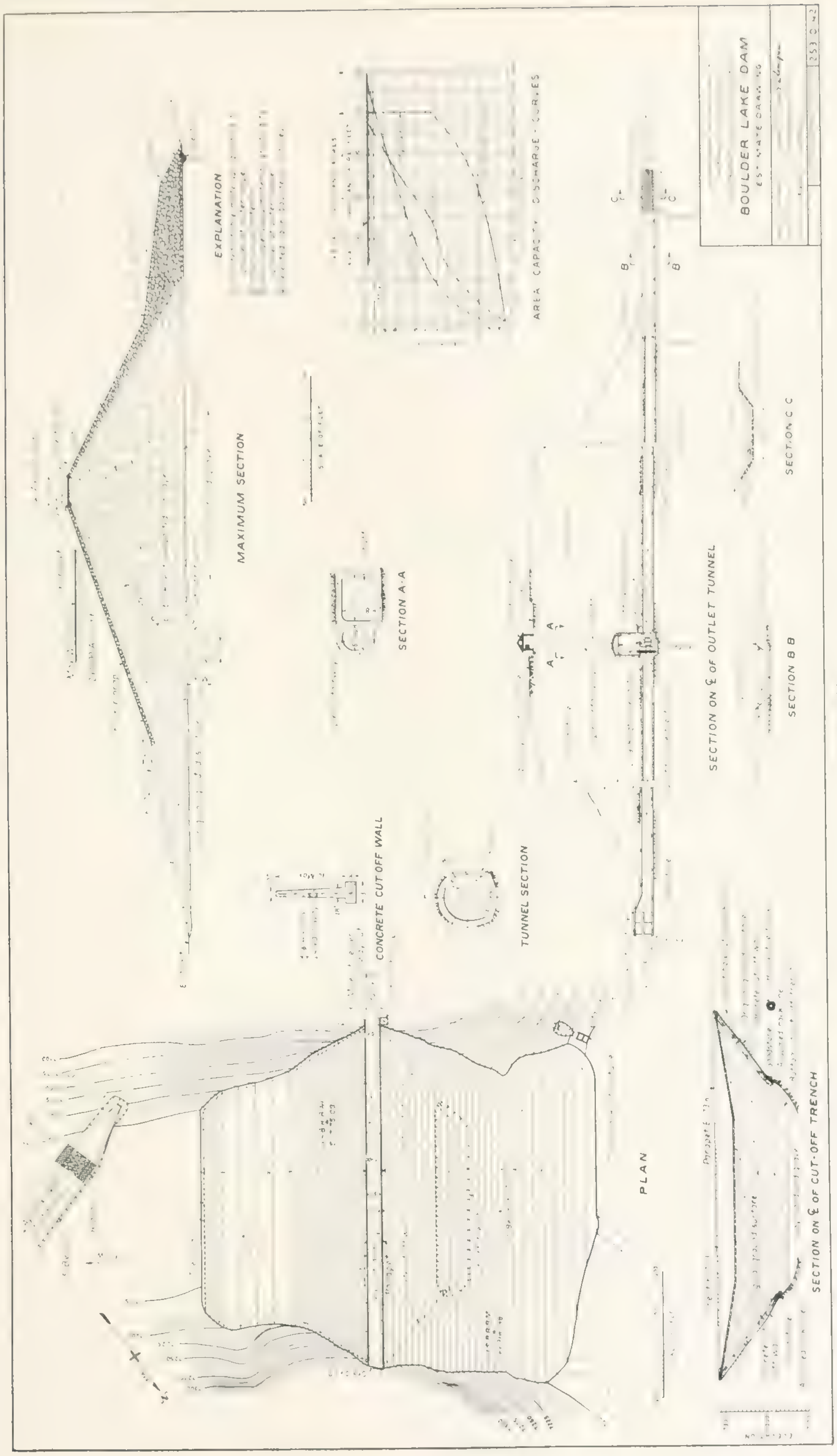
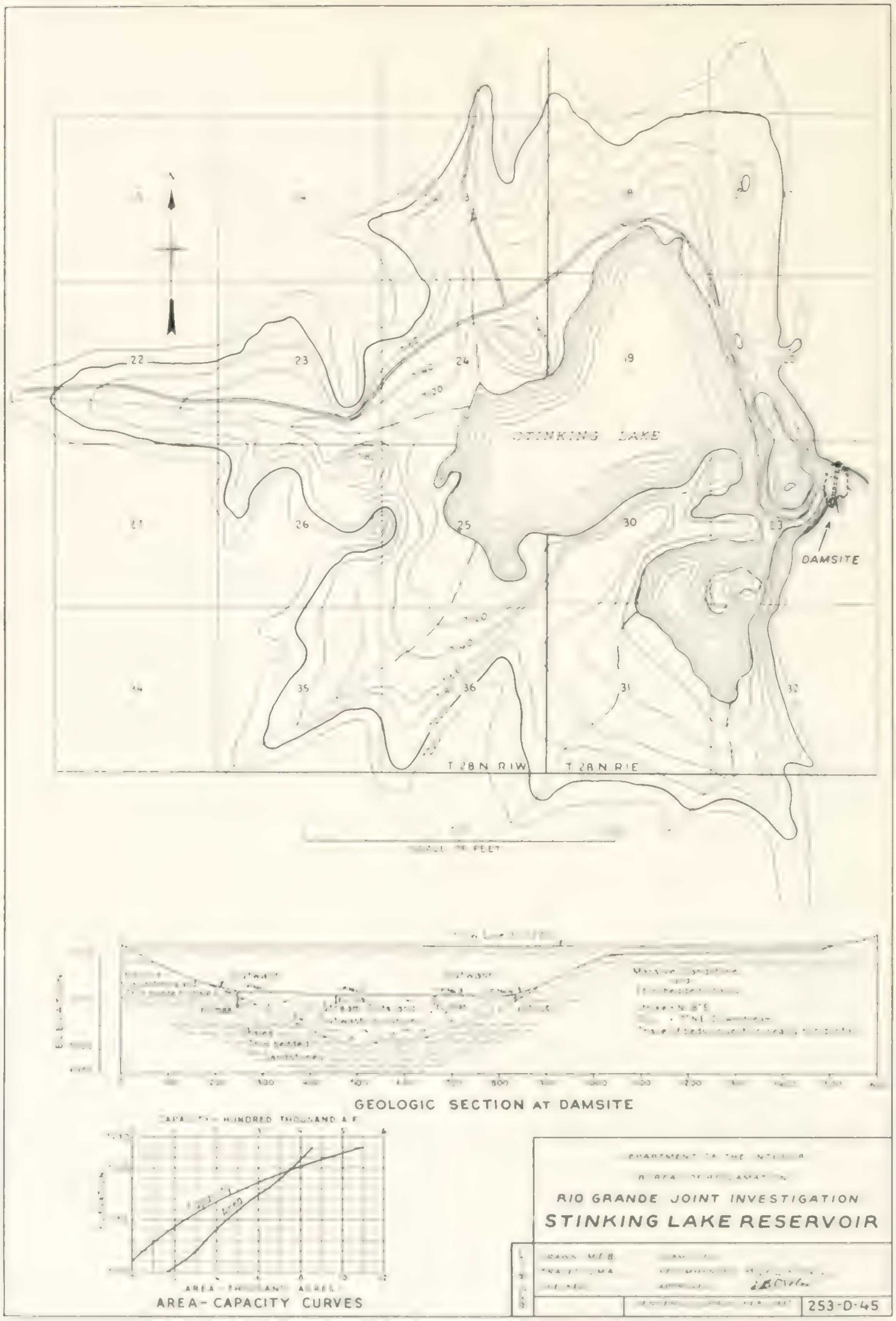

BOULDER LAKE DAM
EXPLANATION
MAXIMUM SECTION
AREA CAPACITY DISCHARGE CURVES
SECTION A-A
CONCRETE CUT OFF WALL
TUNNEL SECTION
SECTION ON ℄ OF OUTLET TUNNEL
SECTION B B
SECTION C C
PLAN
SECTION ON ℄ OF CUT-OFF TRENCH

FIGURE 116



STINKING LAKE
DAMSITE
T 28N R1W
T 28N R1E
GEOLOGIC SECTION AT DAMSITE
AREA-CAPACITY CURVES
RIO GRANDE JOINT INVESTIGATION
STINKING LAKE RESERVOIR
253-D-45

Figure 117

concrete parapets and curbs. The upstream slope is 3:1 with 3 feet of rock riprap. A 20-foot berm is placed at elevation 7,215 and a 5:1 slope from there down. The downstream slope is 2:1 to elevation 7,220, 8:1 to elevation 7,200, and 2:1 for the remainder of the rock-fill section. A typical concrete cut-off with a maximum height of 10 feet, extends upward along both abutments of the rock slopes connecting with a 30-foot cut-off trench in the deep stream wash materials in the central portion. Stripping for a depth of 18 inches is provided over the entire dam area. Depth to bedrock under the dam across the channel has not been determined, and for this reason a 30-foot deep cut-off trench was assumed. Should further investigations disclose shallow depths to bedrock the estimated cost may be somewhat reduced.

An emergency spillway located on a saddle about 3½ miles from the dam site was estimated as a lump-sum item. No data are available on this feature. The drainage area does not exceed 15 square miles.

An 11-foot diameter concrete-lined horseshoe tunnel will serve as an outlet tunnel only and for stream diversion during the construction period. It is planned to install two 79-inch diameter ring follower emergency gates and two 66-inch needle valves for outlet operation, in the gate chamber. An 8- by 11-foot concrete-lined shaft, with a 6-foot diameter concrete spiral stairway shaft, will extend from the control chamber to the top of the dam, where the shaft is surmounted by a control house, provided with a 15-ton hoist. It is planned to install a gas-electric generator set in the control house for lighting and operating purposes. At the upstream end of the tunnel the trash rack structure is placed at the bottom of the tunnel inlet, there being sufficient capacity below this elevation to allow for reservoir silting. The outlet end of the tunnel discharges into the stilling basin and from there into a 50-foot bottom width canal section some 1,400 feet long.

It will require approximately two seasons to construct this dam. The nearest railroad shipping point is at Dulce, N. Mex., a distance of 20 miles over fair roads. About 3 miles of new road will be required to reach the dam.

Stinking Lake Reservoir

Stinking Lake dam site is located about 9 miles west of El Vado, N. Mex., in the Jicarilla Apache Indian Reservation. It is 33 miles via highway from the nearest railroad shipping point, Chama, N. Mex., all but 8 miles of which is improved and graveled. The reservoir is entirely in Government land under the supervision of the United States Indian Service. Data and designs on this dam are here included since it may eventually be chosen as a terminal reservoir in place of Boulder Lake Reservoir in the event plan A is adopted.

Summary of estimate data.

Storage capacity—active	500,000 acre-feet.
Spillway capacity	Emergency only.
Outlet capacity at low levels	1,000 second-feet.
Elevation—top of dam	7,230.
Reservoir water-surface elevation	7,220.
Maximum height of dam	115 feet.
Total estimated cost—dam and reservoir	$1,400,000.
Topography of reservoir and geologic sections	Figure 117.
General plan and sections	Fig. 118
Preliminary estimate	Table 8.

The reservoir area at elevation 7,220 is 8,500 acres, all located in the Indian reservation. No clearing will be required in the reservoir area. No improvements exist.

Geology.—There has been no opportunity to study in detail the regional geology or the immediate valley conditions. Inspection has shown that the present stream pattern is the result of antecedent or imposed erosion. The gaps forming the dam sites at Stinking and Boulder Lakes are unusual topographic features.

The reservoir basin is underlain by shales and soft sandstones, the same as those in the Boulder Lake Basin. They overlie the more massive sandstone at the dam site but are part of the same series. All rock is heavily mantled with detrital silts, in which the present lake is found. The strata strike N. 18° E. and dip 5°–7° NW. The water table is believed to be tributary to the stream, considering the character of the bedrock and the presence of the existing lake.

There is no reason to suspect unusual or unsatisfactory dam site conditions to develop in an exploratory program other than considerable depth of foundation silts in the stream bed. One test pit near the right abutment encountered sandstone at 8½ feet. Due to the intermittent stream character the canyon has partially filled with detrital wash and stream silts, which, from logs of test pits 1, 2, 3, and 4, appear to be predominantly silt with some boulders and rock fragments. The sides of the canyon are irregularly covered with talus and wash which becomes progressively deeper toward the toe of the slopes.

The dam site is a canyon carved in massive sandstone with alternating shale layers. The rock becomes progressively more shaly both up and downstream from the immediate proposed dam axis. The dip is a fortunate occurrence insofar as seepage must pass through the beds rather than circulate along bedding planes. The rock is somewhat fractured, a condition accentuated by surface weathering, so that some grouting may be required. No faulting was noted in the area and no soluble salt seams were noted in the stratigraphic column.

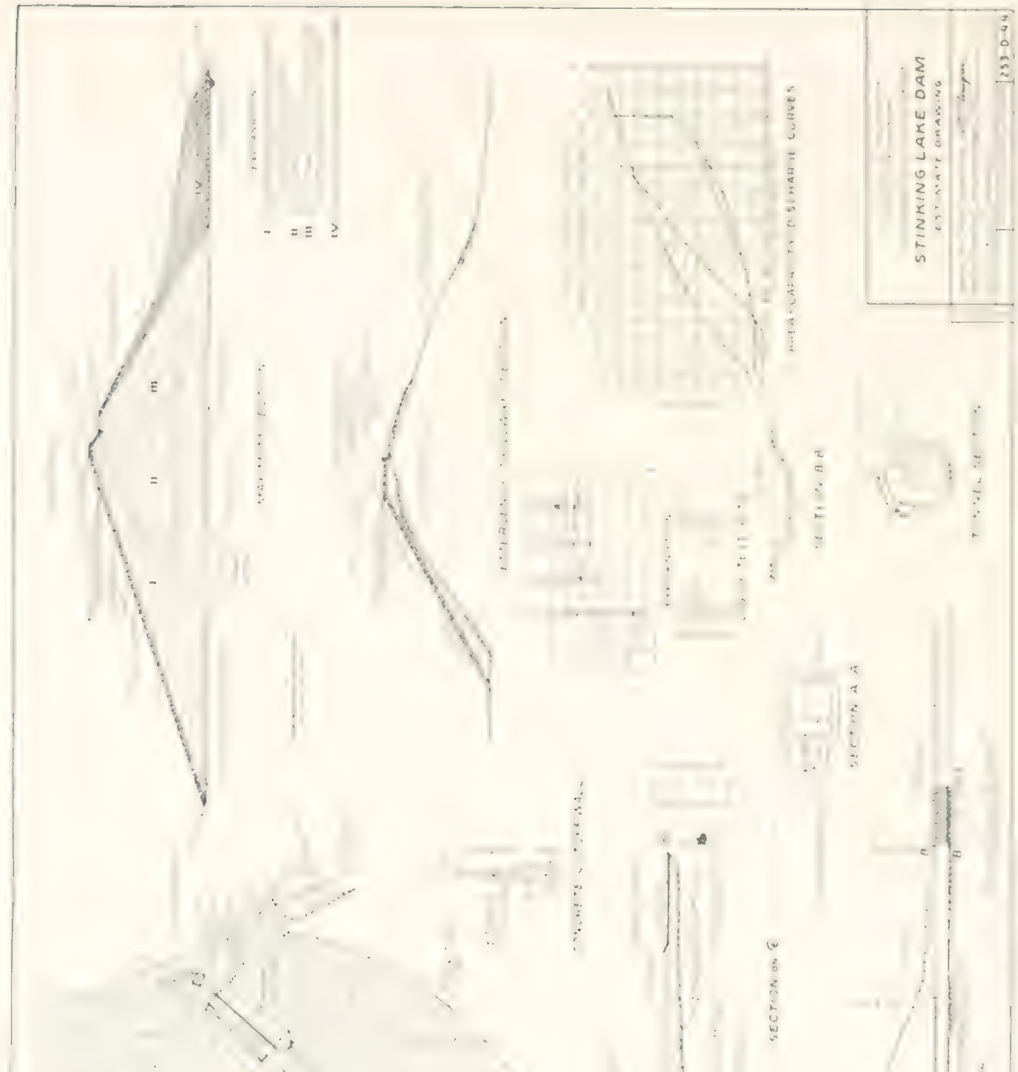


FIGURE 118

There is no question as to the stability of the bedrock. The stream silts, however, are moderately porous and may upon saturation become soft and plastic. It may become necessary to remove those entirely under the dam.

Dam.—The compacted embankment type of dam was selected. It is estimated that embankment materials in adequate amount are available about 1 mile downstream from the site. Sources of sand and gravel are uncertain but they are thought to be available about 10 miles from the site, for the limited amount of concrete necessary for this dam. Figure 118 shows the general plan and sections of the proposed dam.

TABLE 8.—*Stinking Lake Dam, preliminary estimate, Jan. 30, 1937*

[illegible], elevation 7,230; normal water surface, elevation [illegible]

[Storage capacity, 550,000 acre feet; spillway capacity, emergency only; diversion capacity, none; [illegible]]

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
EARTHWORK								
Excavation, common:								
Stripping, dam foundation	46,100	Cubic yard	$0.30	$13,830			$0.30	$13,830
Stripping, borrow pits	68,000	Cubic yard	.30	20,400			.30	20,400
[illegible]	32,100	Cubic yard	.40	12,840			.40	12,840
[illegible] inlet and outlet channel	28,500	Cubic yard	.40	11,400			.40	11,400
Borrow, and transportation to dam	1,319,200	Cubic yard	[illegible]	329,800			.25	329,800
Excavation, rock:								
Cut-off wall	120	Cubic yard	4.00	480			4.00	480
Tunnel inlet and outlet channel	7,600	Cubic yard	2.50	19,000			2.50	19,000
Outlet tunnel and shaft	3,500	Cubic yard	10.00	35,000			10.00	35,000
Borrow, and transportation to dam	158,800	Cubic yard	.75	119,100			.75	119,100
Embankment:								
Earth fill compacted	1,221,100	Cubic yard	.10	122,110			.10	122,110
Dumped rock on downstream slope	175,000	Cubic yard	.20	35,000			.20	35,000
Riprap rock on upstream slope	53,500	Cubic yard	.40	21,400			.40	21,400
Backfill about structures	500	Cubic yard	.50	250			.50	250
Gravel for roadway	1,000	Cubic yard	2.50	2,500			2.50	2,500
Hand-placed rock	1,500	Cubic yard	1.00	1,500			1.00	1,500
GROUTING AND DRAINAGE								
Drilling:								
Grout holes not over 25 feet deep	4,300	Linear foot	1.00	4,300			1.00	4,300
Drain holes	1,000	Linear foot	1.00	1,000			1.00	1,000
Weep holes	200	Linear foot	1.00	200			1.00	200
Pressure grouting: Tunnel, shaft, and cut-off wall	10,400	Cubic foot	1.00	10,400	$0.80	$8,320	1.80	18,720
Drain tile:								
12-inch diameter clay tile in gravel	2,200	Linear foot	.70	1,540	.45	990	1.15	2,530
8-inch diameter clay tile in gravel	600	Linear foot	.60	360	.30	180	.90	540
6-inch diameter clay tile in gravel	700	Linear foot	.50	350	.20	140	.70	490
4-inch split tile	600	Linear foot	.30	180	.20	120	.50	300
CONCRETE WORK								
Concrete:								
Cut-off wall not formed	120	Cubic yard	11.25	1,350	4.15	498	15.40	1,848
Cut-off wall formed	300	Cubic yard	13.00	3,900	4.60	1,380	17.60	5,280
[illegible] emergency spillway	445	Cubic yard	15.00	6,675	4.15	1,847	19.15	8,522
Trash rack, transition, and stilling basin	450	Cubic yard	16.00	7,200	4.60	2,070	20.60	9,270
Below operating floor of gate chamber	630	Cubic yard	13.25	8,348	4.15	2,614	17.40	10,962
Tunnel, shaft, and gate chamber	1,620	Cubic yard	15.25	24,705	4.15	6,723	19.40	31,428
Control house	20	Cubic yard	20.75	415	4.60	92	25.35	507
METALWORK								
Metal:								
Trash rack	50,000	Pound	.02	1,000	.08	4,000	.10	5,000
Reinforcement steel	302,000	Pound	.02	6,040	.03	9,060	.05	15,100
[illegible]	20,100	Pound	[illegible]	1,005	.10	2,010	.15	3,015
Water stops	120	Linear foot	[illegible]	30	[illegible]	18	[illegible]	78
2 79-inch ring-follower gates and control mechanism	164,000	Pound	[illegible]	6,560	[illegible]	39,360	[illegible]	45,920
2 66-inch needle valves and control mechanism	140,000	Pound	[illegible]	4,200	[illegible]	30,800	[illegible]	35,000
[illegible]	35,000	Pound	[illegible]	[illegible]	[illegible]	6,650	[illegible]	7,350
Gas-electric generator set and equipment	(1)		(1)	200	(1)	800	[illegible]	1,000
Miscellaneous metalwork	3,500	Pound	[illegible]	350	[illegible]	[illegible]	[illegible]	700
Grout and drain pipe	2,400	Pound	[illegible]	120	[illegible]	168	[illegible]	288
MISCELLANEOUS ITEMS								
Items:								
Control house except concrete	(1)		[illegible]	300	[illegible]	1,200	(1)	1,500
Transporting freight except cement for Government from Chama, N. Mex., to the dam site (33 miles).	360	[illegible]	3.30	1,188			[illegible]	1,188
Highway construction	8	Mile	10,000.00	[illegible]			10,000.00	[illegible]
Right-of-way	8,500	Acre		[illegible]	[illegible]	[illegible]	10.00	85,000
Subtotal				917,226		204,420		1,121,646
Contingencies, 15 percent								168,247
Total estimated field cost								1,289,893
Investigations and surveys							(1)	5,000
Engineering and inspection, 5 percent								64,494
Superintendence and accounts, 1 percent								12,899
General expense, 2 percent								25,798
Total estimated cost								1,398,084
Cost per acre-foot of storage								2.54

[1] Lump sum.

Plate 119

The dam is 1,560 feet long at the crest and attains a maximum height of 115 feet. The dam has a freeboard of 10 feet with a top width of 30 feet, of which 10 feet only is at the very top. The balance is a 20-foot graveled roadway on a back slope berm at water level elevation 7,220. The upstream slope is 3 : 1 on the main portion of the dam and 2 : 1 on the right-hand blanket section below the emergency spillway, overlain with 3 feet of rock riprap. The downstream slope is 2 : 1 to elevation 7,160, 7 : 1 to elevation 7,135, and 2 : 1 for the remainder of the rock-fill section. A typical concrete cut-off wall, with a maximum height of 10 feet, extends along both abutments of the rock slope, connecting with a 30-foot depth cut-off trench in the deep overlying earth material in the central portion. Stripping for a depth of 18 inches was estimated over the entire dam area.

It is doubtful whether the reservoir water surface will ever rise above elevation 7,220, but as an added safety factor an emergency spillway 100 feet long at elevation 7220 was located in the right abutment section. The roadway in this section was made of concrete and the dam slopes paved with hand-placed riprap.

An 11-foot diameter concrete-lined horseshoe tunnel will serve as an outlet tunnel only. No diversion will be required during construction and the entrance to the outlet structure is above the present water surface in the lake. It is planned to install two 79-inch diameter ring follower emergency gates and two 66-inch needle valves for outlet control and operation in the tunnel gate chamber. An 8-foot by 11-foot concrete-lined shaft containing a 6-foot diameter concrete spiral stairway shaft will extend from the control chamber to the top of the dam, where the shaft is surmounted by a control house equipped with a 15-ton hoist. It is planned to install a gas-electric generator set in the control house for lighting and operation purposes.

At the upstream end of the tunnel the trash-rack structure is placed at the bottom of the tunnel inlet, there being sufficient capacity below this elevation to allow for reservoir silting. The outlet end of the tunnel discharges into the stilling basin and from there into a 50-foot bottom width canal section some 1,400 feet long.

Construction.—It will require approximately two construction seasons to construct this dam.

The nearest railroad shipping point is at Chama, N. Mex., on the narrow gage Denver & Rio Grande Western Railroad Co. line from Alamosa to Durango, a distance of 33 miles over fair roads.

Power Development on Chama River

Future utilization of the water delivered by the San Juan-Chama diversion is not known at present. Preliminary studies indicate that a terminal storage capacity of 300,000 acre-feet would enable deliveries into the Chama River, averaging 350,000 acre-feet, to be regulated to irrigation demands from 1911 to date without shortage.

Sufficient terminal storage capacity is available in Boulder Lake for such reregulation with plan A. Elevation of the outlet portal of the tunnel above the reservoir is 7,401 and high water level in Boulder Lake is 7,305. The outlet of Boulder Lake is 7,175. A minimum head of 96 feet can thus be used for power above Boulder Lake but for 2 months of the year no water could be delivered. There would also be severe fluctuations from year to year with considerable fluctuations from month to month. The average head available at Boulder Lake Dam would probably be about 90 feet. Thus only 180 feet of the total fall between the end of the diversion canal and El Vado Reservoir can be utilized for power.

If Stinking Lake is used for a terminal reservoir instead of Boulder Lake only about 150 feet of total fall can be made available for power above El Vado.

Elevation of the divide tunnel portal on the "B" plan is 7,575 or 174 feet higher than on the "A" plan. Surveys on Willow Creek below the portal and above El Vado Reservoir show four reservoir possibilities as follows:

Name	Maximum storage capacity, acre-feet	Estimated cost of dam and reservoir only
Chama (no. 1)	40,000	$575,000
Parkview (no. 2)	20,000	375,000
Upper Willow Creek (no. 3)	164,000	1,850,000
Lower Willow Creek (no. 4)	239,000	1,900,000
Total	463,000	$4,700,000

For irrigation use only, either of the Willow Creek sites is probably sufficient for reregulation of the diverted waters with only minor shortages in low years. The cost per acre-foot for terminal storage will be higher than for an equivalent amount of reregulation on the "A" plan.

For the dual purpose of power and irrigation, "B" plan offers the more interesting possibilities, especially when power and storage opportunities below El Vado are also considered.

The lower Willow Creek Reservoir sites (nos. 3 and 4) have been surveyed by the United States Geological Survey and detailed surveys of the dam sites were made by the Bureau. The Chama and Parkview (nos. 1 and 2) dam sites were mapped by the Bureau but storage capacity was not determined as the reservoirs are small and would be kept full to maintain power head. No drilling has been done at any of the sites but geological reconnaissances at each of them have shown favorable conditions.


SAN JUAN CHAMA
TRANSMOUNTAIN DIVERSION
RESERVOIRS FOR POWER DEVELOPMENT
253-D-179
ABIQUIU DAM SITE
CAÑON DE CHAMA DAM SITE
WILLOW CREEK DAM SITE No 4
WILLOW CREEK DAM SITE No 3
WILLOW CREEK DAM SITE No 2
WILLOW CREEK DAM SITE No 1
TUNNEL

FIGURE 170

Power output at the Willow Creek sites can be increased by diversion of the Chama River at Chama into Willow Creek above the Parkview (no. 2) Reservoir. A fly line for this diversion was surveyed and the diversion cost estimated at $190,000 for a canal of 500 second-feet capacity, 3.2 miles long.

Development at and below El Vado Reservoir.—A reconnaissance of the Chama River below El Vado Reservoir shows two additional power and storage possibilities, as follows:

Name	Maximum storage capacity acre-feet	Estimated cost for dam and reservoir only	Maximum head in feet
Abiquiu site	286,000	$3,339,800	190
Canon De Chama site	92,600	2,500,000	165
El Vado Reservoir [1]	226,000		176
Total	604,600	$5,839,800	531

[1] Constructed.

These reservoir sites have been surveyed by the United States Geological Survey. The Bureau surveyed the Abiquiu dam site in detail and rough estimates of cost were prepared. The cost of the Canon de Chama Reservoir has been estimated by comparison with the other sites. Two geological reports are available on the Abiquiu site, both of which indicate favorable conditions for a dam of the proposed height. No geological reports are available on the Canon de Chama site. No drilling was done at either site. Figure 120 is a general map of the Chama watershed showing potential power development. Figure 121 shows topography at the Abiquiu and Canon de Chama sites.

Total power possibilities on Willow Creek and Chama River.—Potential power output has been calculated by using all of the reservoirs above described including the Chama River diversion to Willow Creek.

Data for power studies

Reservoir	Capacity, acre-feet			Head in feet	
	Total	Active	Dead	Maximum	Minimum
Willow Creek No. 1 (Chama)	40,000	0	40,000	90	90
Willow Creek No. 2 (Parkview)	20,000	0	20,000	50	50
Willow Creek No. 3	164,000	124,000	40,000	151	103
Willow Creek No. 4	239,000	199,000	40,000	210	129
El Vado	226,000	126,000	100,000	176	130
Canon de Chama	92,600	60,400	32,200	165	120
Abiquiu	286,000	250,000	36,000	190	98
Total	1,067,600	759,400	298,200	1,032	720

Estimated mean annual controlled flow:		
Chama River at Abiquiu	acre-feet	320,000
San Juan-Chama Diversion	do	320,800
Total	do	640,800
Equivalent flow	second-feet	885

Mass curves of the reconstructed flow at Abiquiu from 1916 to date indicate that the flow of 885 second-feet can be maintained prior to 1931 with very little storage regulation and with large blocks of secondary power available every year. The critical period from 1931 to early in 1936 has been studied in more detail, a summary of which is shown in the following table.

The studies indicate a firm power output of 250,000,000 kilowatt-hours per year with an average output of 400,000,000 kilowatt-hours per year over long periods.

Effect of power regulation of Chama River on irrigation supply for Rio Grande.—If the Chama River and San Juan waters are regulated for power only in accordance with the schedule shown in table 9, the mean monthly flow below Abiquiu Reservoir becomes approximately 53,000 acre-feet in minimum years. The maximum monthly irrigation demand for the Middle Rio Grande Conservancy District is about 100,000 acre-feet. With Rio Grande modified only to the extent of such a modification at the Abiquiu dam site, the resulting flows would at practically all times equal or exceed the diversion requirements for the Middle Rio Grande Conservancy District. The minor modifications needed to fully meet such requirements would not materially affect power output.

TABLE 9.—*Summary of power production—Chama River—Period 1931–35, inclusive*

Date	Outflow from Abiquiu River in 1,000 acre-feet	Power output in million kilowatt-hours by all plants [1]		
		Primary	Secondary	Total
(1)	(2)	(3)	(4)	(5)
1931				
January	82.4	22.5	7.6	30.1
February	74.4	20.4	6.7	27.1
March	82.4	22.5	7.5	30.0
April	79.2	21.8	7.1	28.9
May	71.4	22.5	7.7	30.2
June	5.5	21.8	7.2	29.0
July	9.4	22.5	7.5	30.0
August	82.4	22.5	7.5	30.0
September	79.2	21.8	7.2	29.0
October	82.4	22.5	7.5	30.0
November	79.2	21.8	7.2	29.0
December	82.4	22.5	7.5	30.0
Total	810.3	265.1	88.2	353.3
1932				
January	82.4	22.5	7.6	30.1
February	77.0	21.1	7.0	28.1
March	82.4	22.5	7.5	30.0
April	79.2	21.8	7.3	29.1
May	7.0	22.5	7.5	30.0
June	31.8	21.8	21.3	43.1
July	70.1	22.5	25.9	48.4
August	59.4	22.5	21.0	43.5
September	51.1	21.8	18.2	40.0
October	53.6	22.5	19.0	41.5
November	51.3	21.8	18.1	39.9
December	45.4	22.5	12.7	35.2
Total	690.7	265.8	173.1	438.9
1933				
January	82.4	22.5	7.5	30.0
February	74.4	20.4	6.7	27.1
March	82.4	22.5	7.7	30.2
April	79.2	21.8	7.2	29.0
May	31.5	22.5	7.5	30.0
June	6.3	21.8	14.5	36.3
July	65.8	22.5	23.4	45.9
August	61.2	22.5	21.8	44.3
September	42.6	21.8	7.2	29.0
October	82.4	22.5	7.5	30.0
November	79.2	21.8	7.3	29.1
December	82.4	22.5	7.5	30.0
Total	769.8	265.1	125.8	390.9

[1] Based on over-all efficiency of 80 percent.

TABLE 9.—Summary of power production, [illegible]—Continued

Date	Outflow from Abiquiu Reservoir, acre-feet	Power output in million kilowatt-hours		
		Primary	Secondary	Total
(1)	(2)	(3)	(4)	(5)
[illegible]				
January	82.4	[illegible]	[illegible]	30.0
February	[illegible]	20.4	6.7	27.1
March	82.4	22.5	7.5	30.0
April	36.2	21.9	0	[2] 21.9
May	40.5	22.5	0	22.5
June	79.7	21.8	0	21.8
July	82.4	22.5	0	22.5
August	65.9	22.5	0	22.5
September	[illegible]	21.7	0	21.7
October	[illegible]	22.5	0	22.5
November	[illegible]	21.8	0	21.8
December	48.8	[illegible]	0	[illegible]
Total	740.8	265.2	21.7	286.9
[illegible]				
January	50.4	22.6	0	22.6
February	47.9	20.5	0	20.5
March	19.8	[3] 7.4	0	7.4
April	74.6	21.8	7.2	[4] 29.0
May	82.4	22.5	7.5	30.0
June	66.3	21.8	7.4	29.2
July	46.0	22.5	7.5	30.0
August	48.6	22.5	7.6	30.1
September	46.4	21.8	7.3	29.1
October	47.0	[illegible]	7.6	30.1
November	43.5	21.8	7.2	29.0
December	45.0	22.5	7.5	30.0
Total	617.9	250.2	66.8	317.0
1936				
January	[illegible]	22.5	7.5	30.0
February	[illegible]	21.1	7.0	28.1

[2] Output cut [illegible] percent due to poor outlook for water.
[3] Shortage of 15.1 million kilowatt-hours of firm power.
[4] Run-off forecast favorable—returned to normal output.

Power market.—The census of 1930 shows a total population of 500,000 in the Arkansas, Rio Grande, and San Juan valleys, within a 200-mile radius of the center of the proposed power development. Growth curves based upon census data beginning in 1910 and projected to 1950 indicate a population on the latter date of 550,000.

Per-capita annual power production in Colorado in 1935 was 517 kilowatt-hours while in New Mexico it was 453. From 1920 to 1935 the per-capita production in Colorado increased from 423 to 517 kilowatt-hours, while in New Mexico, during the same period, the increase was from 42 to 453 kilowatt-hours. Total power production within the area in 1935 was 264,000,000 kilowatt-hours based upon per-capita production in each State.

Predictions of power consumption in 1950 are hazardous but it is not unreasonable to assume that if cheaper power becomes available, potential per-capita consumption may reach 1,000 kilowatt-hours and total consumption 546,000,000 kilowatt-hours.

The total potential output of plants herein outlined probably cannot be utilized by 1950 but the system lends itself to construction by units as the need arises.

Cost of power development.—Installations and total estimated costs for the seven plants herein outlined are as follows:

Station	Kilowatt installed capacity	Cost of dam	Total cost
Chama No. 1	[illegible]	$575,000	$1,145,000
Parkview No. 2	3,300	375,000	804,000
Upper Willow Creek No. 3	[illegible]	1,850,000	2,370,000
Lower Willow Creek No. 4	11,500	1,900,000	2,475,000
El Vado	12,000	(1)	[illegible]
Cañon de Chama	12,000	[illegible]	3,136,000
Abiquiu	16,000	3,310,000	4,156,000
Total	68,500	10,540,000	14,710,000

[1] Constructed.

State Line Reservoir

General.—This reservoir (fig. 122) has been under consideration for many years and was specifically mentioned in the Rio Grande Compact. The site was also considered by the Middle Rio Grande Conservancy District to provide river regulation and flood control.

Three sites have been considered: the original State line site about 1½ miles below State Line Bridge and 1½ miles above the Colorado-New Mexico State line; the lower State line or Costilla site at the mouth of Costilla Creek; and the Ute Mountain site about 10 miles south of the State line.

A summation of pertinent data on the three sites considered follows:

Site	Height of dam required in feet		Storage capacity acre-feet	
	Elevation, 7,500	Elevation, 7,510	Elevation, 7,500	Elevation, 7,510
State line	80	90	294,000	[illegible]
Costilla	135	145	399,338	636,716
Ute Mountain	185	195	[illegible]	700,000

The original site was considered by the Middle Rio Grande Conservancy District in 1929. It offers the lowest and probably the cheapest dam of the three but its capacity is limited by right-of-way difficulties above elevation 7,500. At this elevation its capacity is only 294,000 acre-feet. Its height would only be 80 feet, but foundation conditions appear to be the least satisfactory of the three sites.

No. 2 site (Costilla site) offers ample capacity for a moderate height of dam but has underground water conditions quite unfavorable. At this lower elevation of the river, additional storage space becomes available in the basin just above the mouth of Costilla Creek.

Disclosure of the conditions at each of the above sites by drilling prompted a further search in a section of the river where ground water conditions obviously were more favorable. Ute Mountain site is the result of this search.

Reservoir geology.—The reservoir area presents two distinct geological conditions. The San Luis Hills near the northern end of the basin are a geologic arch of dense impervious andesite in an old peneplain surface, while the valley proper above the hills is a downwarp with troughs at the east and west ends of the arch. This warping was attended by considerable contemporary faulting.

This downwarping was following by a cycle of erosion which, south of the hills, resulted in a wide valley much deeper than the present gorge, but which was arrested at the San Luis Hills by the harder composition of the basement rock, thus permitting the deposition in the San Luis Basin of silts and alluviums in strata of varying origin and permeability.

Coincident with, and eventually overcoming the erosion, intermittent vulcanism from sources at or near Ute Mountain, San Antonio Mountain, and other similar buttes in the vicinity, spread recent basalts over the southern portion to eventually fill the older channel to its present level, the older San Luis Hills arch acting as an effective barrier to prevent any considerable flow into the northern area.

Thus, north of the arch, ground water must necessarily be, and is, near the surface, but where the river emerges into the porous basalts downstream the water table drops below the stream surface. It is 66 feet below the stream at State Line site, 39 feet below at Costilla site, and again on the surface at Ute Mountain. The water table gradient in the trough from the San Luis Hills to Ute Mountain is 2 feet per mile while the river gradient is approximately 8 feet.

The water table apparently has the form of a broad trough in the bottom of which is a local rise under the immediate stream channel, indicating seepage losses from the stream. However, no appreciable loss developed in a careful series of seepage measurements made by the bureau in the spring of 1937. Below Ute Mountain, springs are visible along the base of the canyon walls but the gain measured at Embudo is not greater than may be expected from side drainage.

Why the water table approaches the stream surface below Ute Mountain is important but poorly understood. Drilling has shown that no basement andesite or granite approaches the surface sufficiently to form a bottle-neck, nor is it likely that interflow clay beds Ute are alone responsible. No clay beds were found at Mountain, but they were observed further downstream.

Permeability of the basalts which form the entire floor and sides of the reservoir basin south of the San Luis hills is the most important consideration in the selection of a dam site. In this basin, the basalt flow contacts, enhanced by columnar jointing should prove quite permeable. Water tests in the drill holes confirm this belief. A dam at any of the sites, to create a reservoir for irrigation and power purposes where long hold-over is required, may be of questionable usefulness by reason of heavy leakage. For flood protection, tightness is not a factor of prime importance since losses around the dam can hardly damage the structure and all water will eventually return to the stream.

Summing up the situation, the area north of the San Luis hills is underlain and surrounded by dense, crystalline rocks which are watertight. Numerous springs abound in the area; nearly everywhere the water table is within a few feet of the surface. No visible springs feed the river in its cut through the hills, but the dense character of the rock allows no leakage from the river channel.

A dam 40 feet high at the north end of this canyon would impound 170,000 acre-feet of water but the cost of right-of-way would far exceed the cost of the dam. There would, however, be no questionable features as to its watertightness.

South of the San Luis hills the problems multiply rapidly. Approximately 60 square miles of basalt flows are included in the basin above the Ute Mountain site, 14,000 acres of which will be under the flow line of the reservoir. Throughout the area the water table is beneath the river and the possibility of extensive leakage from the reservoir becomes important. Eight miles below the Ute Mountain site the basin again becomes restricted by a ridge of hills, not unlike the San Luis hills, but the cut-off to underground flow is not as definite nor is the throat as restricted.

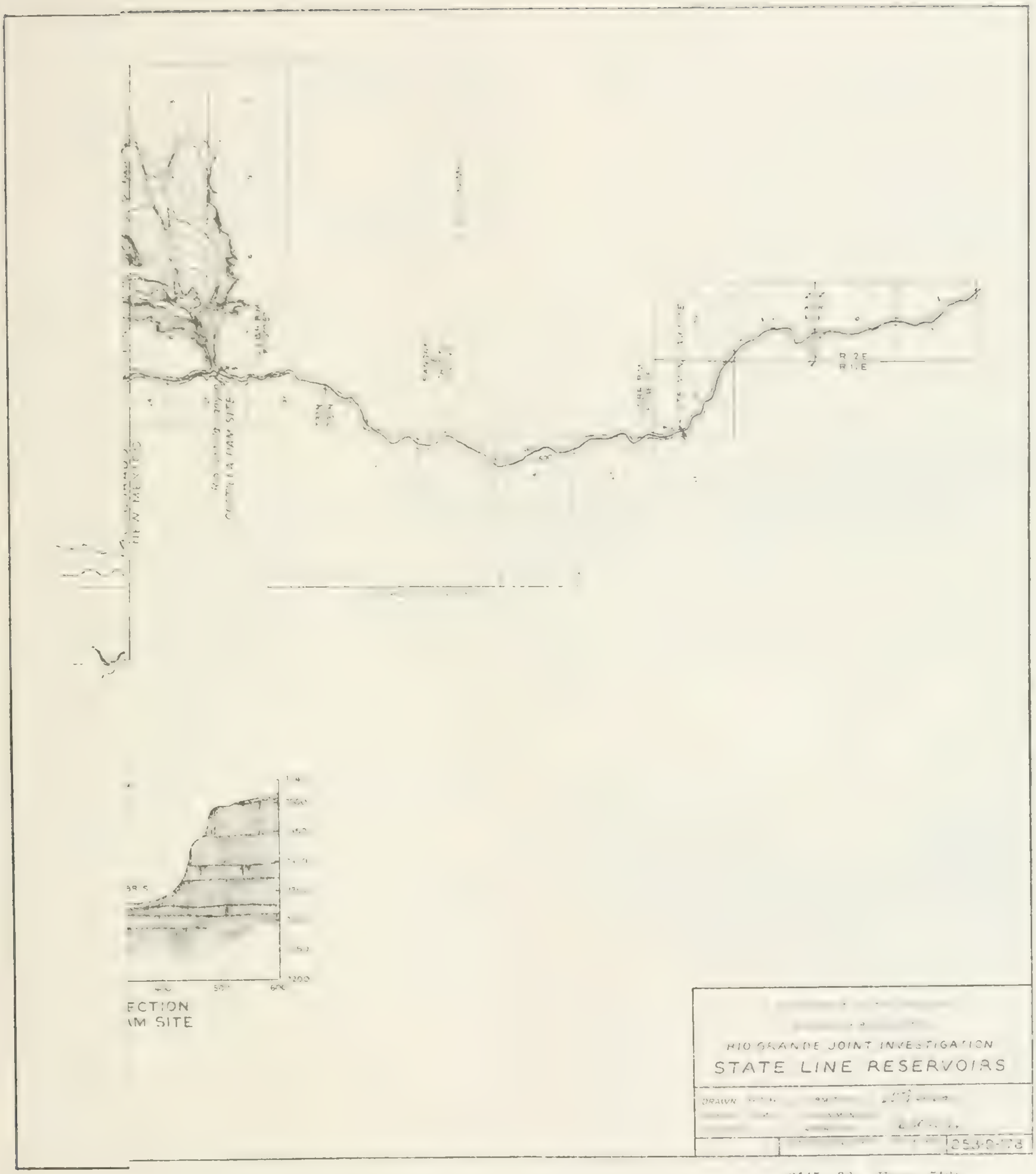
South of the San Luis hills, this latter location probably offers the best opportunity for a dam with a tight reservoir but unfortunately beginning at a point about 3 miles south of the Ute Mountain site the river bed increases its gradient rapidly and to secure a reservoir of a capacity comparable to the sites above would require a dam more than 300 feet in height and with a longer crest length than any of the other sites.

The Ute Mountain site was finally adopted to determine estimated costs. While it is the most expensive of the three sites, it has the advantage of large capacity for flood control without unduly flooding San Luis Valley, and of high power head if such development should prove desirable.

Dam-site geology—State bridge dam site.[1]—This site has been ably considered in a geological report by Kirk Bryan. The following brief attempts merely to summarize the available information. The site has been partially diamond drilled but no pits have been dug.

The dam site is a narrow canyon eroded into a horizontal series of basalt flows containing erratic interflow clay beds. Both abutments are of horizontal basalts, each individual flow having dense centers and perme-

[1] [illegible] of the State Line dam site, Kirk Bryan, for the [illegible] of New Mexico, Albuquerque, August [illegible].



2115—38 (Face p. 516)

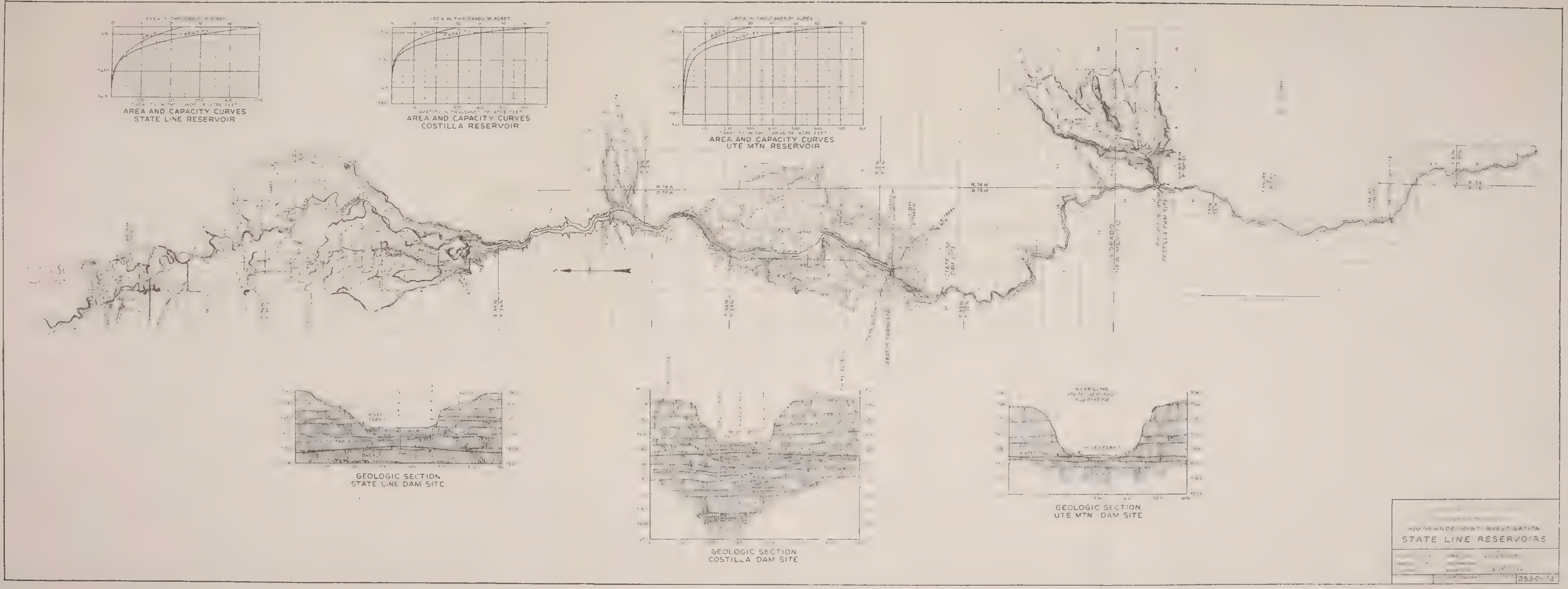


FIGURE 122

2143—28 (Face p. 516)

able, vesicular tops or flow contacts. Columnar jointing is prominent but widening by rim creep has not progressed to the extent found at the lower sites. Undoubtedly many of the vesicular zones will prove to be quite permeable. Several interflow clay beds occur between flows; a 30- to 40-foot seam occurs on both abutments above elevation 7,430, while another thinner seam is encountered (5 to 8 feet) beneath the foundation at elevation 7,395.

The foundation is mantled with a thin veneer (10 to 15 feet) of silt and gravel in which there are many large basalt boulders. Typical talus or loose angular rock and rock fragments line the foot of the basalt cliffs and similar material covers the higher clay seam so that it is not exposed.

The water table is found 66 feet beneath the river and probably does not substantially rise to the left for many miles. With storage it undoubtedly would rise on the andesite several hundred feet back from the right abutment, where the impervious basement comes to the surface in the San Luis Hills. There is reason to suspect that seepage past the dam and reservoir may prove excessive.

Costilla dam site.—This site was diamond drilled and no test pits were considered necessary. Five holes were drilled across the proposed axis and one at the head of Costilla Gulch.

The rock narrows is an erosional canyon cut into horizontal basalt flows, which in this locality has only a few inconsequential interflow clay beds. The older valley into which these basalts accumulated was probably wide and quite deep, the bottom possibly mantled with gravels below the basalt. These basalts extend back from both abutments for many miles, in which the water table rises slowly to the sides (5 to 10 feet per mile) but is 40 feet beneath the stream level and 46 feet beneath the abutments. This bulge must indicate present stream loss.

Both basalt abutments are made up of numerous flows with dense centers and vesicular tops and contacts. Normal columnar jointing is evident and some widening by rim creep was noted. Abutment drilling encountered only a few interflow clay seams, none of which were over 3 inches thick. A 3-foot seam was encountered 85 feet below the river under the left abutment. The foundation is covered with 8 to 10 feet of sand, gravel, and incorporated talus boulders of a porous character. The canyon walls are uncovered except for a normal thin talus lying along the base.

There is no doubt as to the stability of this basalt, considering its hard character and the absence of clay beds. A concrete structure can probably be utilized. The jointed character of the abutments make grouting necessary to bind the blocks into a unit mass. A high permeability is indicated.

Ute Mountain dam site.—The selected Ute Mountain site was not drilled but two diamond drill holes were located downstream and to the west in determining the water-table conditions. No test pits were utilized.

The lower drill hole shows that no impervious basement rock approaches the surface and that no thick or extensive interflow clay bed is present for at least 250 feet below the stream bed. Ute Mountain, undoubtedly a source area for some of the valley basalts, lies 4 miles to the northeast and the deeper flows around this vent may be more massive and thereby somewhat less permeable. The mass may then form a partial barrier to downstream percolating ground waters on the left side of the valley. However, no such mass is found on the right side where horizontal basalts extend back for many miles. A drill hole (elevation 7,575 approximately) encountered a thick interflow clay member from 40 to 78 feet and struck water at 247 feet or only 15 feet above the river.

Both abutments are of horizontal basalts but the number and thickness of possible interflow clay beds has not been determined. The basalt flows are similar to those at the upper sites but the deeper canyon has allowed more creep with the resultant widening of columnar joints. In fact, this axis is one of the lowest remaining areas where such slump has not seriously disrupted the walls or given rise to landslides. Downstream, possible sites become increasingly less attractive. Water tests in the drill hole located 3 miles downstream (elevation 7,318) were unfavorable and much fracturing of the rock was evident. The foundation basalts should prove the equal of those encountered in the other sites.

The water table is probably within a few feet of the river surface, for immediately downstream springs appear at the surface while the water level in the lower drill hole remained at stream elevation. Overburden conditions are not severe; the foundation should contain only 10 to 15 feet of sand, gravel, and basalt boulders, while the base of the basalt cliffs are lined with normal talus deposits.

Summary of estimated data

Ute Mountain Dam:

Storage capacity	452,000 acre-feet.
Spillway capacity	15,000 second-feet.
Outlet capacity (required at elevation 7,470).	4,500 second-feet.
Elevation top of dam	7,508.
Maximum reservoir water-surface elevation.	7,500.
Maximum height of dam	198 feet.
Total estimated cost, dam and reservoir	$2,600,751.
Topography of reservoir and geological sections.	Fig. 122.
General plan and section	Fig. 123.
Preliminary estimate	Table 10.

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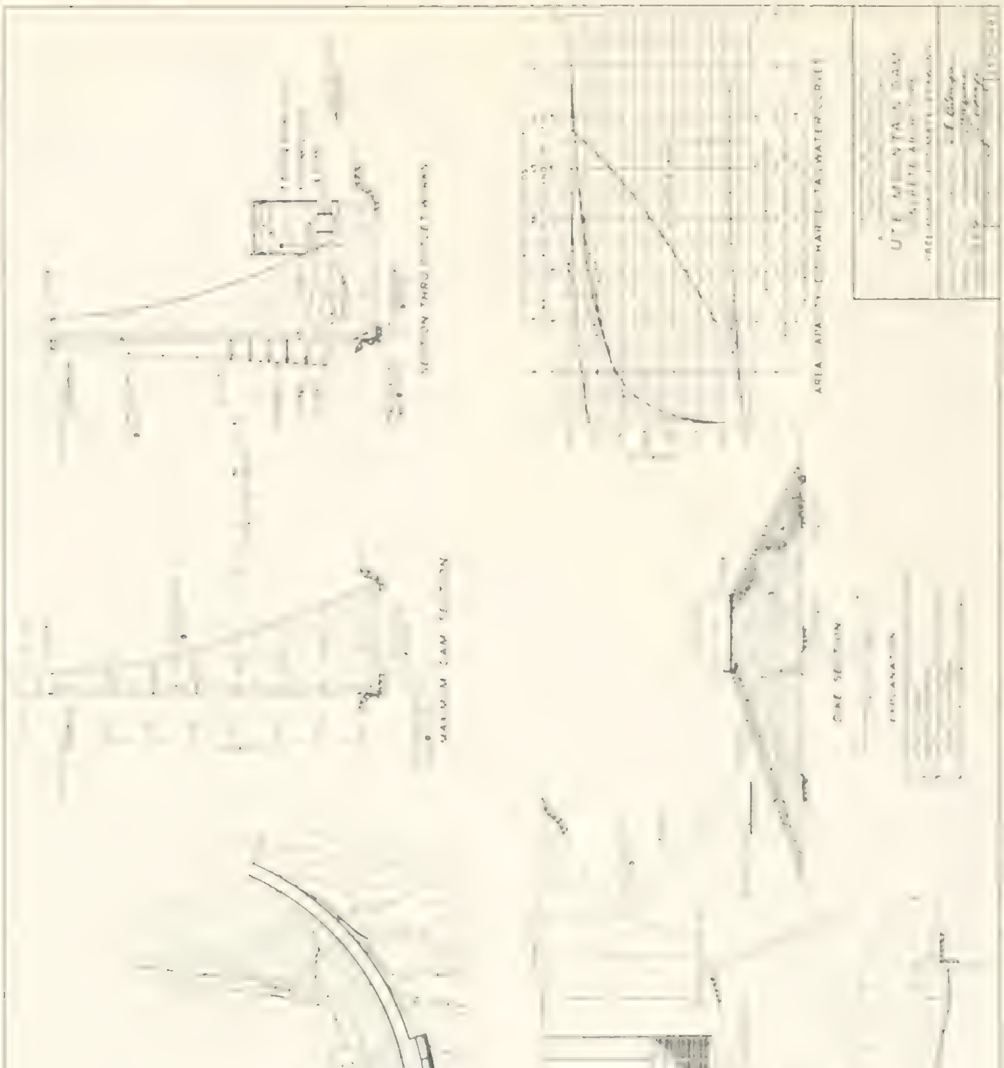
General plan and section	Fig. 123.
Preliminary estimate	Table 10.



Reservoir.—The reservoir area at elevation 7,500 is 20,000 acres, about 2,000 acres of which will require clearing of brush and willows. Nine thousand five hundred acres has no improvements, and is believed to have no value. Cost of right-of-way for the balance is estimated as follows:

	Acres	Cost of right of way
Cultivated area	[1] 1,960	$137,200
Hay land	[2] 4,220	168,800
Meadow land	[3] 4,320	129,600
Total	10,500	435,600

[1] $70 per acre. [2] $40 per acre. [3] $30 per acre.

It is assumed that all utility lines in the reservoir area will be abandoned and replacement will not be necessary. About 14 miles of roads will be submerged, and the cost of highway relocation is estimated as follows:

Relocate 2¼ miles of highway at $6,000	$13,500
Bridge piers and abutments	15,000
Raise old bridge spans	8,000
Approach fills, 9,100 cubic yards at $1	9,100
Total cost	45,600

The removal of houses, barns, etc. from the reservoir area will cost approximately $20,000.

Dam.—The almost perpendicular walls of the narrow basalt canyon indicate that the most economical and feasible type of dam for this site is a concrete arch with an abutment spillway. However, there are possibilities for a diamond-head overflow buttress dam, but limitations of time and funds did not permit an estimate of cost for this type. No tests were made to determine the strength of the rock, and no drilling of the foundation was done. There is nothing to indicate any geological defects at this dam site. It is assumed that there is an average of 8 feet of sand and gravel above the basalt bedrock of the river bed. About 2,000 feet of earth dike is required on the left abutment. Material for embankment is scarce, but probably enough for the dike can be obtained on the hills in the vicinity and from excavation.

A straight overflow concrete gravity dam at this site would require approxmately (165,000 cubic yards) 90 percent more concrete than the arch dam and nearly double the cost of the dam.

The adopted plan is an arched concrete dam with an axial radius of 275 feet. The maximum dam section will be 198 feet high with a crest width of 13 feet 5 inches and a thickness of 62 feet 10 inches at elevation 7,325. The crest at elevation 7,508 is surmounted by two concrete parapets. This crest elevation was necessary in order to provide an 8-foot freeboard for the dike section.

The concrete arch terminates in a gravity thrust block section on the left abutment beyond which is the spillway.

Owing to the large outlet discharge requirements, spillway discharges will occur infrequently as outlets are sufficient for normal flood control. The spillway is of an emergency nature and consists of a straight concrete lined channel spilling into the ravine downstream from the left abutment of the dam. The channel is 65 feet wide inside and joins the thrust block on the river side. Three 20 feet long by 17 feet high radial gates will control the spillway flows. The outlet works will consist of trash racks with cleaning mechanism operated from the top of the dam, three 84-inch steel-lined conduits through the dam, each of which is controlled on the downstream end by an 84-inch ring follower emergency gate, and a 72-inch needle valve. A bulkhead gate is provided to close the conduits at the face of the dam for maintenance purposes. The outlets will discharge 4,500 second-feet with the reservoir elevation 7,467. A roadway to the valve house will be provided in the canyon below the dam.

Joining the spillway on the left will be an earth dike. The dike is of the typical rolled embankment type, 25 feet in maximum height with a 30-foot top width, 3 to 1 upstream and 2 to 1 downstream slopes. The upstream slope is protected by 3 feet of rock riprap and the downstream face with dumped rock. A concrete cut-off wall is placed on rock underneath the dike. A thin mantle of soil covers the rock under the dike.

It is planned to grout the foundation of the arch dam with holes 150 feet deep and at 5-foot centers. No doubt a certain amount of grouting will be required under the dike section. Owing to the thinness of the arch and the high altitude, cooling of the concrete will not be necessary other than possibly a certain amount in the lower base elevations which probably can be done with river water; however, detailed design studies will indicate the necessary requirements. The contraction joints of the arch are placed at 40-foot centers. Internal drainage is provided.

Construction schedule.—The construction schedule for this dam should cover a two-season period to allow ample time for the fabrication of gates and valves, otherwise no difficulty should be encountered during construction unless the acquisition of right-of-way should prove difficult.

Preliminary estimate.—The preliminary estimate of this dam is given in table 10. The estimate includes a lump sum of $40,000 for diversion of the river and unwatering the foundations. No specific plan has been worked out for diversion. However, the construction schedule will indicate the best plan. It is anticipated that diversion will be made through a conduit in the base of the dam and by leaving blocks at low elevations for maximum flows. Unit prices in the estimate are

based on early 1937 prices and may vary considerably over a period of time. The contract cost for concrete items includes the cost of hauling the cement and furnishing aggregate. Sand and gravel can probably be procured at Sunshine Valley, a distance of 6 miles from the dam site.

TABLE 10.—*Ute Mountain Dam, preliminary estimate, Aug. 12, 1937*

[illegible]

[Storage capacity, 452,000 acre-feet; spillway capacity, 15,000 second-feet; required outlet capacity, 4,500 second-feet]

Item	Quantity		[illegible]nished by the contractor		[illegible] the Government		Summary	
	[illegible]	Unit	[illegible]	Total cost	[illegible]	Total cost	[illegible]	[illegible]
[illegible]								
[illegible]	(1)		[illegible]	[illegible]			[illegible]	[illegible]
[illegible]								
[illegible]								
[illegible]	[illegible]	[illegible]	$1.00	[illegible]			$1.00	4,000
[illegible]	11,800	Cubic yard	.30	[illegible]			.30	[illegible]
[illegible]	10,000	Cubic yard	.25	[illegible]			.25	2,500
[illegible]	2,600	[illegible]	.75	1,950			.75	1,950
[illegible]	10,000	Cubic yard	.60	6,000			.60	6,000
[illegible]	500	Cubic yard	1.00	[illegible]			1.00	500
Borrow, and transportation to dam	70,000	Cubic yard	.35	24,500			.35	24,500
[illegible]								
[illegible]	16,900	Cubic yard	3.00	50,700			3.00	50,700
[illegible]	[illegible]	Cubic yard	5.00	2,250			[illegible]	2,250
Toe drains and cut-off trenches	[illegible]	Cubic yard	6.00	600			[illegible]	600
[illegible]	12,000	Cubic yard	1.25	15,000			[illegible]	15,000
[illegible]	15,000	Cubic yard	1.75	[illegible]			[illegible]	26,250
[illegible]								
[illegible]	55,000	Cubic yard	[illegible]	5,500			.10	5,500
Dumped rock on downstream slope	11,400	Cubic yard	[illegible]	[illegible]			.20	2,280
Riprap rock on upstream slope	9,300	Cubic yard	[illegible]	[illegible]			.40	3,720
[illegible]	10,000	Cubic yard	[illegible]	6,000			.60	6,000
Gravel for roadway and spillway	2,500	Cubic yard	2.00	5,000			2.00	5,000
[illegible]	5,000	Cubic yard	.40	2,000			40	2,000
[illegible]								
[illegible]								
Grout holes not over 25 feet deep	5,000	Linear foot	[illegible]	3,750			.75	3,750
[illegible]	1,250	Linear foot	1.00	1,250			1.00	1,250
[illegible]	2,500	Linear foot	1.25	[illegible]			1.25	3,125
[illegible]	24,000	Linear foot	1.75	42,000			1.75	42,000
Drain holes not over 25 feet deep	[illegible]	Linear foot	1.00	500			1.00	500
[illegible]	1,000	Linear foot	[illegible]	1,500			1.50	[illegible]
[illegible]	3,750	Linear foot	2.00	7,500			2.00	7,500
[illegible]	500	Linear foot	1.00	500			1.00	500
Anchor bars and grouting in place	800	Linear foot	.40	320	$0.30	[illegible]	[illegible]	560
[illegible]								
[illegible]	49,000	Cubic foot	1.00	[illegible]	.75	36,750	[illegible]	[illegible]
[illegible]	400	Cubic foot	2.00	[illegible]	[illegible]	360	2.90	1,160
Drain tile:								
[illegible]	[illegible]	Linear foot	.80	[illegible]	.60	180	1.40	420
[illegible]	1,500	Linear foot	.60	900	.40	600	[illegible]	1,500
9-inch diameter clay tile in gravel	1,300	Linear foot	[illegible]	650	.30	390	[illegible]	[illegible]
[illegible]	6,400	Linear foot	[illegible]	4,480	.20	1,280	[illegible]	[illegible]
[illegible]								
Concrete:								
[illegible]	85,000	Cubic yard	5.75	[illegible]	3.25	276,250	[illegible]	765,000
[illegible]	[illegible]	Cubic yard	9.00	[illegible]	[illegible]	2,100	[illegible]	7,140
[illegible]	270	Cubic yard	11.00	[illegible]	4.00	1,080	15.00	4,050
[illegible]	880	Cubic yard	10.50	[illegible]	3.75	3,300	14.25	12,540
[illegible]	150	Cubic yard	21.00	[illegible]	4.00	[illegible]	25.00	3,750
Parapets and curbs on embankment section	775	Cubic yard	18.00	13,950	4.00	[illegible]	22.00	17,050
[illegible]	[illegible]	Cubic yard	[illegible]	1,106	4.00	[illegible]	18.75	1,406
[illegible]	900	Cubic yard	11.00	[illegible]	4.00	[illegible]	15.00	13,500
Cut-off wall footings	[illegible]	Cubic yard	[illegible]	4,275	4.00	[illegible]	13.50	6,075
[illegible]	[illegible]	Cubic yard	12.00	5,100	4.00	[illegible]	16.00	6,800
[illegible]	850	Cubic yard	10.00	8,500	3.75	3,188	13.75	11,688
[illegible]	100	Cubic yard	21.00	2,100	4.50	[illegible]	[illegible]	[illegible]
Special finishing concrete surfaces	3,000	Square yard	.75	2,250	.05	150	.80	2,400
METALWORK								
Metal:								
[illegible]	126,000	[illegible]	[illegible]	[illegible]	[illegible]	7,560	.08	[illegible]
[illegible]	570,000	Pound	.02	11,400	.035	19,950	[illegible]	[illegible]
[illegible]	5,700	Linear foot	.25	1,425	.40	[illegible]	.65	3,705
Bulkhead gate, frames, and guides	[illegible]	Pound	.02	[illegible]	[illegible]	1,575	.11	1,925
[illegible]	[illegible]	Pound	.03	[illegible]	[illegible]	[illegible]	.11	50,160
[illegible]	[illegible]	[illegible]	.03	8,700	.24	[illegible]	.27	75,300
3 84-inch ring follower gates and operating mechanism	[illegible]	Pound	[illegible]	7,200	.18	43,720	.21	[illegible]
[illegible]	[illegible]	[illegible]	.05	[illegible]	[illegible]	2,400	.13	3,900
Pipe and fittings for contraction joint grouting	[illegible]	[illegible]	.15	3,750	.10	[illegible]	.25	6,250
[illegible]	[illegible]	[illegible]	.10	[illegible]	.10	250	.20	500
[illegible]	[illegible]	Pound	.02	[illegible]	.19	[illegible]	.21	9,450
3 20- by 17-foot radial gates and operating mechanism	[illegible]	Pound	.04	3,000	.11	8,250	.15	11,250
[illegible]	7,500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.20	[illegible]

[1] Lump sum.

TABLE 10.—*Ute Mountain Dam, preliminary estimate, Aug. 12, 19[illegible]*—Continued

Item	Quantity		Material and labor fur[illegible]		[illegible] the Government		[illegible]	
	Amount	Unit	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
MISCELLANEOUS ITEMS								
Items:								
Valve house, except concrete	(1)			2,500		2,500		5,000
Guard rail on roadway	3,000	Linear foot	[illegible]	[illegible]	.50	1,500	1.00	3,000
Gas-electric generator set and equipment	(1)			[illegible]		[illegible]		2,000
Clearing reservoir	2,000	Acre	25.00	50,000			25.00	50,000
Contractor's camp and permanent buildings	(1)					40,000		40,000
Relocation of roads	(1)					45,600		45,600
Removing houses, barns, etc., from reservoir	(1)			20,000				20,000
Right-of-way	10,500	Acre			41.50	435,750	41.50	435,750
Transportation, freight except cement for Government, from Jarosa, Colo., to the dam, [illegible] miles	1,000	Ton	1.20	1,200			1.20	1,200
Subtotal				1,006,261		1,067,613		2,073,874
Contingencies, 15 percent								311,081
Total estimated field cost								[illegible]
Investigations and surveys								25,000
Engineering and inspection, 5 percent								[illegible]
Superintendence and accounts, 1 percent								23,850
General expense, 2 percent								47,700
Total estimated cost								2,600,751
Cost per acre-foot storage								5.75

[1] Lump sum.

FIGURE 124

PART V

SECTION 3.—COLORADO INVESTIGATIONS

Animas-Rio Grande Transmountain Diversion

General Plan [1]

The South Fork of Mineral Creek, Mineral Creek, and Cement Creek will be diverted to a reservoir at Howardsville on the main Animas River a few miles above Silverton, from which a tunnel will pierce the Continental Divide eastward to the Rio Grande about 60 feet above and a mile from the high-water line of the Rio Grande Reservoir.

The diversion from the South Fork of Mineral Creek is at elevation 9,852. The west portal of the main tunnel to the Rio Grande has a bottom grade at elevation 9,697.7 and the east portal at 9,612.

The principal features incorporated in the plan are as follows:

Collection system:		
Earth canal	miles	1.14
Combination section	do	8.62
Bench flume	do	.49
Cut and cover section	do	.85
Tunnel	do	2.56
Total in collection system	do	13.65
Animas-Rio Grande tunnel, 9.5-foot diameter	do	12.98
Howardsville Reservoir, maximum height of dam 255 feet, length 1,500 feet, capacity	acre-feet	53,000

The route traversed by the collection system is characterized by steep, barren side slopes, subject to frequent snowslides. For this reason most of the system has been designed for concrete lining, cut and cover section, or tunnel. The tunnel from Mineral Creek to Cement Creek is the only feasible method of connecting these two creeks, trial lines around the slopes having shown such steep slopes and extensive rockslides that no canal could there be maintained. There is a possibility that some storage can be found to regulate the flow of South Mineral Creek and Mineral Creek. If so, the size and cost of the collection canal can be reduced, but it is questionable whether the savings which may result will equal the cost of reservoir facilities on these creeks.

Howardsville Reservoir and Dam

The high dam required to obtain sufficient storage capacity, and the character of the property to be submerged make for high cost. Howardsville (a group of seven or eight buildings and homes), several old mine buildings at the mouth of Maggie Gulch, together with 5 miles of highway and 3 miles of railroad (narrow gage) are below high-water line. The railroad company has petitioned for abandonment of the tracks. The dam site itself has not been explored by test pits or drilling and there are three possible locations for the dam. If the upper one at the town should finally be selected there may be a considerable decrease in the cost of the dam, for the valley floor rises about 60 feet between the lower and upper sites with only a slight decrease in storage capacity. A rough estimate of cost for the lower site is presented. No detailed plans were prepared.

[1] Fig. 124.

Animas-Rio Grande Tunnel

The main feature of the project is the tunnel from Howardsville Reservoir to the Rio Grande, 12.95 miles in length, and designed for 400 second-feet capacity. Physical conditions at each end limit the available fall and even with the plan here proposed, there will remain a small amount of dead storage in Howardsville Reservoir. The tunnel would have a capacity of 500 second-feet if given 28.4 feet of additional fall, but this will add 1,440 feet to the length and increase the cost by $90,000. Such an increase in capacity may prove desirable to increase water deliveries in late summer.

Water Supply

Altitude run-off curves previously developed for the San Juan-Chama diversion were also used for calculating run-off from the various watersheds on this project. The same period of years, 1916–25, was used in determining a mean run-off for that period, and the same type of annual and monthly curves were applied. Long concurrent run-off records for the Durango and Tacoma stations on the Animas River permit extension of estimates to a longer period. The results are incorporated in figure 126. The figures therein represent the sum of contributions from the individual watersheds of the South Fork of Mineral Creek, Mineral Creek, Cement Creek, Animas River above Howardsville, and Arastre Creek.

The capacity of each diversion ditch receiving an unregulated supply has been made 50 percent greater than the mean daily flow of the maximum mean month for the period 1916–25. The estimated diversion allows for undivertible peak flows above ditch capacities. Peak flows on intercepted tributaries were assumed to have the same relation to peak flows at Durango as the relation of their drainage areas.


RIO GRANDE JOINT INVESTIGATION
HOWARDSVILLE RESERVOIR
AREA-CAPACITY CURVES
DAMSITE NO. 2

It was concluded that undivertible water would be in the proportionate amount that the flow at Durango exceeded a flow of 5,000 second-feet during the day.

In adopting any figure as to the reliable water supply to be obtained for the Animas-Rio Grande diversion or upon which to base an estimated cost per acre-foot, it must be borne in mind that the period 1916 to 1925 was one of comparatively high run-off. Since that time stream flows have been less. (See fig. 127.) For the period from 1927 to 1934, inclusive, the mean diversion would be only 123,250 acre-feet. In the minimum year of 1934 only 43,000 acre-feet could have been diverted, while the maximum in 1911 was 209,100 acre-feet. If a figure of 150,000 is adopted there would have been a full supply in 15 out of 25 years from 1911–35, inclusive, with shortages not exceeding 5,000 acre-feet in two additional years. A supply which could be secured 80 percent of the time would be about 122,000 acre-feet. The 1924–35 mean is 130,725 acre-feet.

Figure 127 presents the progressive 10-year means of divertible water, together with progressive 10-year means for the run-off of other San Juan Basin streams and of the Rio Grande at Del Norte. Significant in this figure is the more rapid drop in discharge of the San Juan River at Rosa as compared to the Animas River. Attention is also directed to the dry cycle which occurred on the Rio Grande from 1899 to 1910,

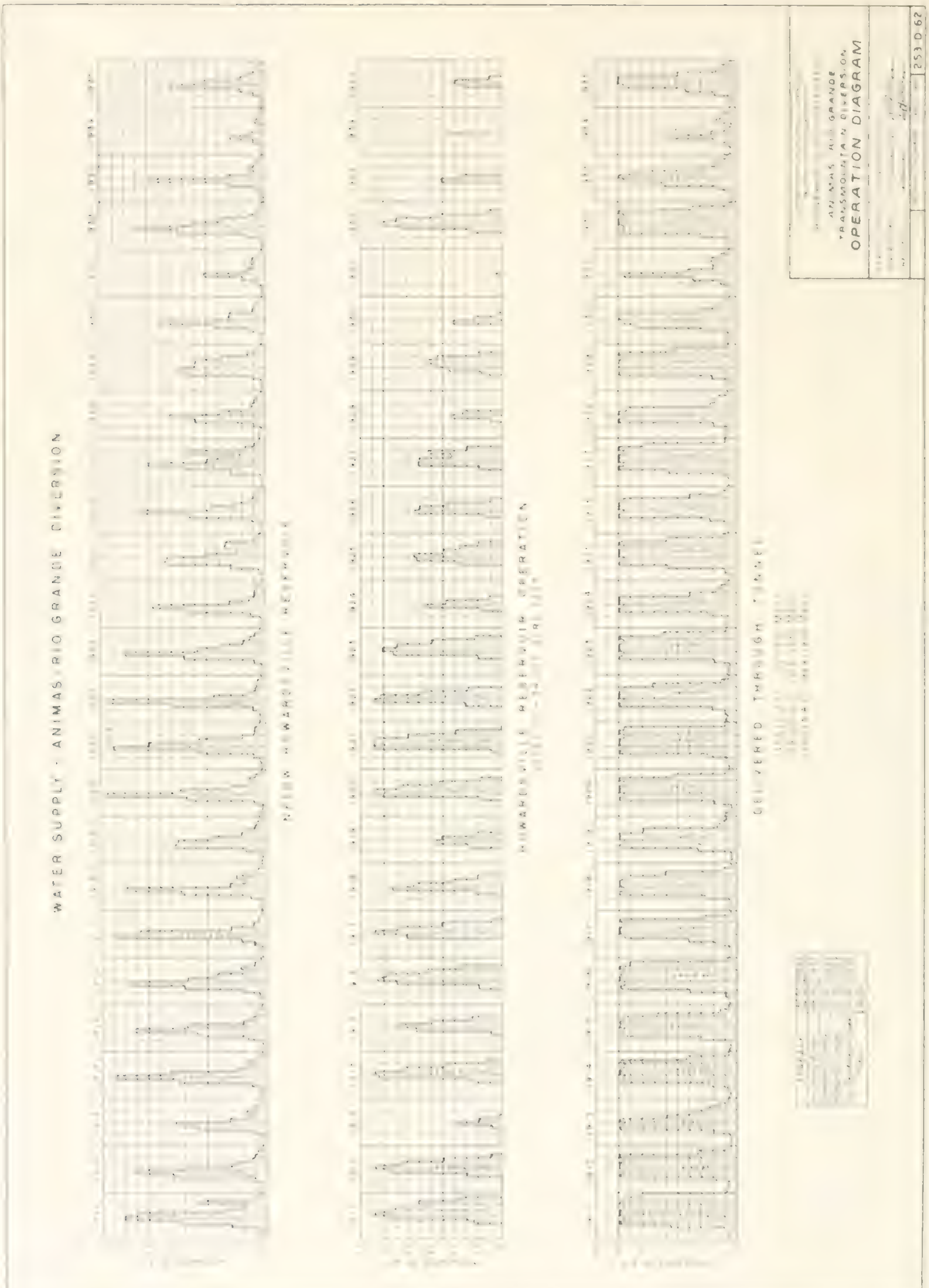
TABLE 11.—*Howardsville dam, preliminary estimate, Jan. 30, 1937*

[Earth embankment: Top of dam elevation 9,800; normal water surface elevation, 9,792; maximum height of dam; 225 feet; drawing no. 253–D–63]

[Storage capacity, 55,000 acre-feet; spillway capacity, 7,000 second-feet; outlet capacity, 500 second-feet, diversion capacity, 3,000 second-feet]

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
RIVER WORK								
Diversion and unwatering foundations	(1)		(1)	$10,000			(1)	$10,000
EARTHWORK								
Excavation, common								
Stripping, borrow pits	$220,000	Cubic yard	0.30	66,000			$0.30	66,000
Stripping, dam foundation	566,000	Cubic yard	.30	169,800			.30	169,800
Spillway	22,000	Cubic yard	.30	6,600			.30	6,600
Borrow, and transportation to dam	3,060,000	Cubic yard	.25	765,000			.25	765,000
Excavation, rock:								
Outlet tunnel	5,600	Cubic yard	10.00	56,000			10.00	56,000
Borrow, and transportation to dam	596,000	Cubic yard	.75	447,000			.75	447,000
Cut-off walls	300	Cubic yard	4.00	1,200			4.00	1,200
Embankment:								
Earth fill	3,250,000	Cubic yard	.10	325,000			.10	325,000
Dumped rock on downstream slope	684,000	Cubic yard	.20	136,800			.20	136,800
Riprap on upstream slope	59,500	Cubic yard	.40	23,800			.40	23,800
Backfill about structures	4,000	Cubic yard	.50	2,000			.50	2,000
GROUTING AND DRAINAGE								
Drilling: Grout holes 50–100 feet deep	12,000	Linear foot	2.50	30,000			2.50	30,000
Pressure grouting, Tunnel and dam	15,000	Cubic foot	1.00	15,000	$1.00	$15,000	2.00	30,000
Drain tile:								
12-inch diameter clay tile in gravel	1,500	Linear foot	.70	1,050	.45	675	1.15	1,725
8-inch diameter clay tile in gravel	1,000	Linear foot	.60	600	.30	300	.90	900
6-inch diameter clay tile in gravel	500	Linear foot	.50	250	.20	100	.70	350
CONCRETE WORK								
Concrete:								
Parapets and curbs	500	Cubic yard	20.00	10,000	4.00	2,000	24.00	12,000
Outlet tunnel lining	2,000	Cubic yard	14.00	28,000	3.60	7,200	17.60	35,200
Gate chamber and trash-rack structure	100	Cubic yard	15.00	1,500	4.00	400	19.00	1,900
Cut-off walls	925	Cubic yard	12.00	11,100	4.00	3,700	16.00	14,800
Spillway channel	4,000	Cubic yard	11.00	44,000	3.60	14,400	14.60	58,400
Control house	25	Cubic yard	20.00	500	4.00	100	24.00	600
METAL WORK								
Metal:								
Trash rack and miscellaneous	50,000	Pound	.02	1,000	.08	4,000	.10	5,000
Reinforcement bars	500,000	Pound	.02	10,000	.03	15,000	.05	25,000
H. P. sluice gates and control apparatus	61,000	Pound	.03	1,830	.22	13,420	.25	15,250
MISCELLANEOUS ITEMS								
Items:								
Control house, except concrete	(1)			200		800		1,000
Gate tender's house	(1)			1,000		2,000		3,000
Subtotal				2,165,230		79,095		2,244,325
Contingencies, 15 percent								336,649
Total estimated field cost (exclusive of reservoir, clearing, right-of-way, highways, telephones, etc.).								2,580,974
Investigations and surveys							(1)	6,000
Engineering and inspection, 6 percent								154,858
Superintendence and accounts, 1½ percent								38,715
General expense, 2½ percent								64,524
Total estimated cost (exclusive of clearing, right-of-way, highways, telephones, etc.).								2,845,071

[1] Lump sum.


WATER SUPPLY - ANIMAS-RIO GRANDE DIVERSION
DELIVERED THROUGH TUNNEL
OPERATION DIAGRAM
253-D-62

the low points of which are still lower than have been reached in the present cycle.

Effect of Diversions on Irrigation From the Animas River

The land classification being made as a part of the Colorado River Basin Investigation authorized by section 15 of the Boulder Canyon Project Act, shows 4,153 acres being irrigated above Durango from the Animas River with little, if any, possibilities of further extension. Below Durango the existing irrigated area is 14,354 acres, with minor possibility of extension.

A tentative study of discharges of the Animas River at Tacoma and Durango, depleted for possible diversions to the Rio Grande for every month from 1911 to date, indicates that no shortages would have occurred at any time on existing rights or future developments now considered feasible.

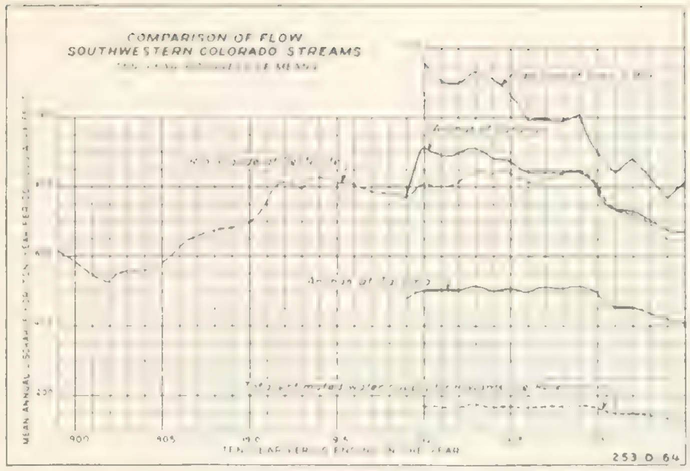


FIGURE 127

TABLE 12.—*Animas-Rio Grande transmountain diversion estimate*

Item	Quantity: Amount	Quantity: Unit	Material and labor furnished by the contractor: Unit cost	Material and labor furnished by the contractor: Total cost	Material furnished by the Government: Unit cost	Material furnished by the Government: Total cost	Summary: Unit cost	Summary: Total cost
Diversions (4) South Mineral Creek, Mineral Creek, Cement Creek, and Arrastre Creek								
Diversion and care of creeks	(1)	4	$500.00	$2,000			$500.00	$2,000
Excavation, common	$1,000	Cubic yard	.75	750			.75	750
Excavation, rock	1,000	Cubic yard	3.00	3,000			3.00	3,000
Backfill	275	Cubic yard	.25	69			.25	69
Puddling backfill	275	Cubic yard	.50	138			.50	138
Concrete, structure	450	Cubic yard	18.00	8,100	3.75	$1,688	21.75	9,788
Radial gates, three 3 by 5 feet, one 8 by 5 feet, two 6 by 5 feet	10,700	Pound	.05	535	.10	1,070	.15	1,605
Hoists	3,800	Pound	.05	190	.25	950	.30	1,140
Reinforcement steel	40,500	Pound	.02	810	.035	1,418	.055	2,228
Rock riprap	400	Cubic yard	1.50	600			1.50	600
Canals:								
Excavation, common	178,000	Cubic yard	.20	35,600			.20	35,600
Excavation, rock	166,200	Cubic yard	.80	132,960			.80	132,960
Backfill	27,000	Cubic yard	.25	6,750			.25	6,750
Trimming foundation	118,000	Square yard	.45	53,100			.45	53,100
Concrete, cut and cover section	3,375	Cubic yard	16.00	54,000	3.75	12,656	19.75	66,656
Concrete, combination section	23,900	Cubic yard	13.00	310,700	3.75	89,625	16.75	400,325
Concrete, bench flume	1,070	Cubic yard	18.00	19,260	3.75	4,013	21.75	23,273
Reinforcement steel	2,934,000	Pound	.02	58,680	.035	102,690	.055	161,370
Rock riprap	50	Cubic yard	1.50	75			1.50	75
Tunnel (D=9.5 feet; L=14,000 feet								
Excavation, all classes	50,120	Cubic yard	9.00	451,080			9.00	451,080
Steel rib supports	169,400	Pound	.08	13,552			.08	13,552
Steel liner plates	464,800	Pound	.08	37,184			.08	37,184
Concrete lining	12,495	Cubic yard	10.00	124,950	5.00	62,475	15.00	187,425
Timbering	137	M ft. b. m.	80.00	10,960			80.00	10,960
Drains	14,000	Foot	1.00	14,000	.50	7,000	1.50	21,000
Tunnel (D=8.75 feet; L=68,560 feet								
Excavation, all classes	206,000	Cubic yard	15.00	3,090,000			15.00	3,090,000
Steel rib supports	757,600	Pound	.08	60,608			.08	60,608
Steel liner plates	2,159,700	Pound	.08	172,776			.08	172,776
Concrete lining	30,000	Cubic yard	16.50	495,000	5.00	150,000	21.50	645,000
Timbering	596	M ft. b. m.	80.00	47,680			80.00	47,680
Drains	55,000	Foot	1.50	82,500	1.00	55,000	2.50	137,500
66-inch needle valve	66,000	Pound	.025	1,650	.245	16,170	.27	17,820
79-inch paradox gate	81,000	Pound	.025	2,025	.21	17,010	.235	19,035
Hoist	3,000	Pound	.025	75	.245	735	.27	810
Miscellaneous metal	20,000	Pound	.025	500	.175	3,500	.20	4,000
Control house	(1)			2,000				2,000
Highway relocation	5	Mile	15,000.00	75,000			15,000.00	75,000
Right of way	825	Acre	50.00	41,250			50.00	41,250
Property damage	(1)					50,000		50,000
Subtotal				5,410,107		576,000		5,986,107
Contingencies, 15 percent								897,916
Total estimated field cost								6,884,023
Investigations and surveys								15,000
Engineering and inspection, 6 percent								413,041
Superintendence and accounts, 1½ percent								103,260
General expense, 2½ percent								172,101
Total estimated cost								7,587,425
Howardsville Dam, total estimated cost								2,845,071
Grand total								10,432,496

[1] Lump sum.

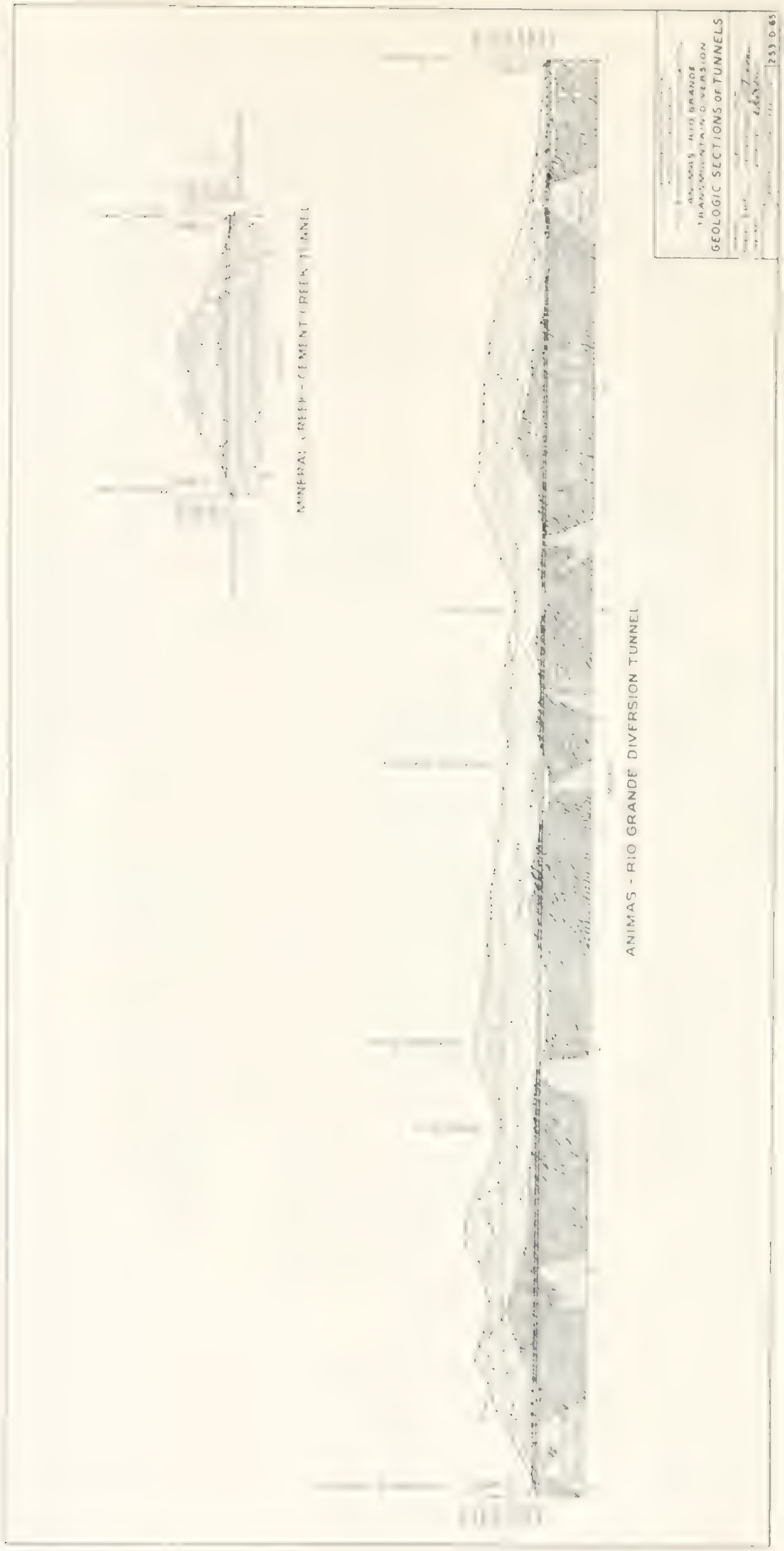

ANIMAS - RIO GRANDE
TRANSMOUNTAIN DIVERSION
GEOLOGIC SECTIONS OF TUNNELS
MINERAL CREEK - CEMENT CREEK TUNNEL
ANIMAS - RIO GRANDE DIVERSION TUNNEL

FIGURE 128

Surveys

A topographic survey of the Howardsville Reservoir on a scale of 200 feet to the inch, and triangulation for the tunnel line from Howardsville to the Rio Grande were carried out during August and the early part of September 1936. Detailed topography was not taken at the dam sites. Trial lines for the collection ditches were run by plane-table at elevation 9,600 and 9,800, the upper line being finally chosen after results of the tunnel survey became available. A trial canal line was run between Mineral Creek and Cement Creek, but the terrain encountered was so difficult that the tunnel between the two creeks was decided upon as the most feasible route for the canal. Topography was taken at each of the diversions from the various creeks.

Geology

Animas-Rio Grande tunnel.—With so little time and funds available for the investigation of this tunnel, the geologic investigation was necessarily limited to a minor field reconnaissance and an office study of available reports. Fortunately, the regional geology was but recently reviewed in a report by W. Cross and E. S. Larson (U. S. G. S. Bulletin No. 843, 1935).

The geologic history of the tunnel area starts with the pre-Cambrian period when the rocks of the time were metamorphosed into schists and gneisses. Then followed successively: Repeated intrusions by granite and related magmas; marine sedimentation with the formation of enormous thicknesses of sandstone, shales, and limestones in some places and local erosion in others; Cretaceous uplift with deep canyon erosion; volcanism with vast deposits and flows of tuffs, breccias, and agglomerates interspersed with periods of erosion. Repeated intrusions shattered, deformed, and altered host rocks in many localities and left innumerable adjacent zones of weakened materials, and finally uplifts and erosion.

Most of the main tunnel will be in Pre-Cambrian crystalline rock but volcanic tuff, flows, intrusions, breccias, and agglomerates will be encountered. The predominate type crystalline rock in this locality is a hard, black, amphibole schist, but undoubtedly areas of gneiss, granite, and other schists will be penetrated. Numerous dikes and other intrusives will be encountered. The series should offer no serious construction problem. The San Juan tuff, which immediately overlies the crystallines and may be penetrated for considerable distances, is formed of volcanic ejects and consists of dark andesite fragments and light colored volcanic ash, loosely consolidated. The tunnel will probably require timbering in this material. A few remnants of limestone and sandstone are found in Cunningham Gulch and the tunnel may encounter some of these sediments, but little remains of them.

The greatest difficulty in construction will probably be encountered near the Howardsville Portal. Here, the rocks are a complex of flows, intrusives, tuffs, breccias, and agglomerates which have been deformed, fractured, altered, and intruded until it is difficult to follow any one formation for more than a few hundred feet. The series will be hard with softer altered zones and the shattered condition may give rise to undesirable water conditions. Support may be needed in sections.

Near the Rio Grande portal the tunnel will enter the Treasure Mountain quartz latite, a formation consisting of uniform latite and andesite flows with some interflow tuffs. Some lensed agglomerates will be encountered and may contain water. The flows are in general massive and competent and no undue difficulty is to be expected in the tunneling operations.

The geologic section shown on figure 128 was made from a regional study of the tunnel line. Because of the complex history, the section may be inaccurate in several sections, especially near the central portions. Only a few exposures of the underlying Archean crystallines have been found and the resultant interpretation of a predominantly crystalline tunnel may not be accurate.

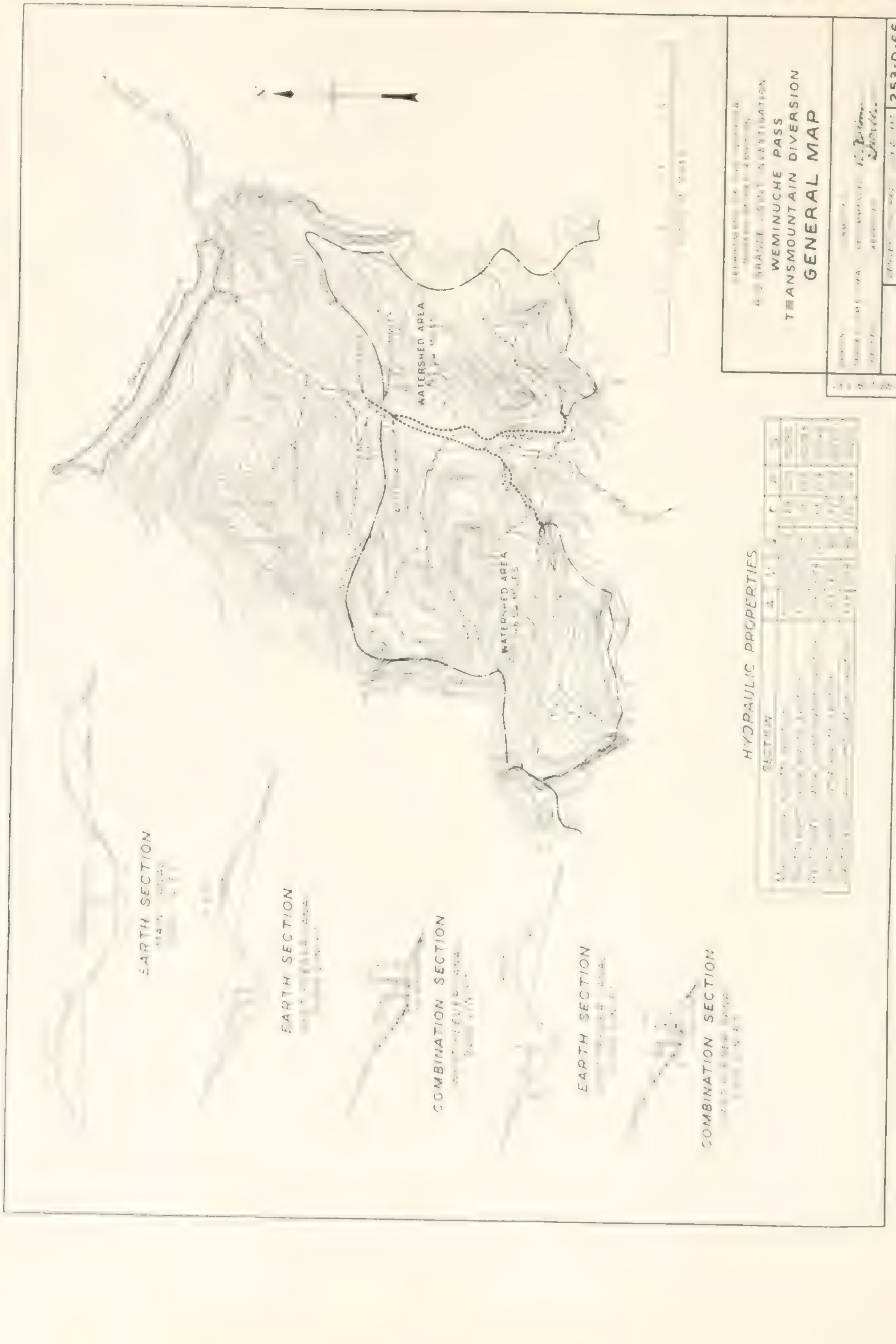
Many questionable zones will be penetrated: formation contacts, alteration of host rocks by intrusives, and loosely consolidated areas in the San Juan tuff or in any agglomerate or volcanic covered detritus. All such conditions will have their effect on the amount and rate of water to be encountered and on stability.

The porous San Juan tuff undoubtedly will contain water, held up as it is by the impervious basement of Pre-Cambrian rock. The elevation of these cyrstallines should be ascertained along the tunnel line by a careful geological investigation and by drilling where it is needed. The tunnel should be located continuously in the impervious Archean rocks, if possible.

Mineral Creek—Cement Creek tunnel.—A profile along the tunnel is shown on figure 128. Both portals should encounter bed rock within a relatively short distance. The bedrock is the Silverton volcanic series so extensively altered and fractured that it is impossible to determine the resultant relationship between the individual flows. Faults, folds, and other structural features are obscure. Such a condition allows only general observations as to the conditions to be expected in the tunnel. Some difficulty is to be expected in the shattered and altered zones through caving ground. Continuout trouble is not expected. Water conditions are nos expected to be severe as the source area is small and the general fractured condition of the rock will make for a general low water table through the area.

Howardsville reservoir and dam sites.—Geological work at this site is of only a preliminary character.

The basin is an erosional valley cut in the Eureka rhyolite and Burns latite flows of the Silverton volcanic



RIO GRANDE JOINT INVESTIGATION
WEMINUCHE PASS
TRANSMOUNTAIN DIVERSION
GENERAL MAP
253-D-66
WATERSHED AREA
WATERSHED AREA
HYDRAULIC PROPERTIES
SECTION
EARTH SECTION
EARTH SECTION
COMBINATION SECTION
EARTH SECTION
COMBINATION SECTION

series. No evidence of an abnormal water table is found and spring and seep occurrences all indicate that any underground flow is directed normally down the river through the river detritus, or possibly in sections of the fractured flow bedrock. The sides of the basin are, in general, mantled with wash and fan materials in local transit to the stream. The flat basin bottom is composed of rounded and subangular pebbles and cobbles with sand and silt to form a firm but porous deposit. It is probably somewhat stratified.

Dam site no. 1, about 1 mile down stream from the highway bridge at Howardsville, is at the upper end of a steep walled gorge. Bedrock is very near the surface on both abutments and probably quite shallow in the foundation. The foundation and abutments of the dam are of the Burns latite, a dark gray, hard flow rock resembling andesite, underlain with Eureka rhyolite which, in turn, probably lies on the San Juan tuff, a compact mixture of angular andesite fragments and ash. The depth of river fill at this locality will probably not be excessive (10 ft.–20 ft.) as some sections of the canyon show rock across the bottom. All of the immediate rock is extremely broken and fractured so that the walls of the canyon appear cracked into small blocks. Weathering has widened these fissures.

Perhaps the most questionable and serious factor concerned is the severe fracturing of all of the foundation and abutment bedrock. Undoubtedly grouting will be required which may reach such proportions as to render the site undesirable.

At dam site no. 2, 3,000 feet below the Howardsville bridge, the bedrock Burns latite is part of the same flow as encountered at the no. 1 dam site. However, the site at this position is out of the canyon section and the valley sides slope more uniformly to the river. The rock in all probability is equally as fractured as that at no. 1 with with less steep slopes, the joints have not had the same opportunity to expand and so an appearance of a tighter, less fractured rock is afforded. It is believed, however, that drilling will indicate its inherent fractured condition.

Bedrock is exposed only on the right abutment, about 40 feet above the railway grade. A mantle of glacial boulders and fragments covers the rest of the area together with large angular talus blocks and detritus derived from the immediate higher land and is apt to be 20 to 30 feet deep. The left abutment overburden is mainly outwash from a nearby gully probably 10 to 20 feet deep, modified by creep movement and incorporated glacial detritus. It is likely that all of this overburden would be removed during construction. The river at this point is flowing on coarse river gravels embedded in considerable sand and silt, with rock probably within 20 to 40 feet. Extensive grouting will be required to eliminate possible abutment and foundation seepage which may otherwise prove to be excessive.

At dam site no. 3, located about 1,000 feet below the Howardsville Bridge, the entire area is mantled with various detritus.

The right abutment is a large alluvial fan made up of torrential debris carried down Brendel Gulch during floods. This detritus is a coarse mixture of angular boulders and fragments embedded in sand and silt. Probably 75 percent or more consists of large rock inclusions. It is believed to be fairly compact but its porosity and the manner in which it will act when saturated has not been determined. Bedrock, probably deep beneath the debris, will be the Burns quartz latite. The left abutment is mantled with outwash, composed of angular fragments and rock embedded in silt and sand, the whole being somewhat modified by soil creep. It is probable that bedrock is within 10 to 20 feet of the surface. Depth to bedrock in the channel is estimated at 50 feet.

Perhaps the most questionable feature at this dam site is the character of the right abutment outwash fan. Tests to determine its reaction to conditions similar to those that will be imposed by the dam should be made. The fan of the right abutment is as much in the process of formation today as at any time in the past, by frequent torrential floods. The depth of overburden will minimize the requirement for grouting of the bedrock.

The points in favor or against each of the possible dam sites are so widely varied that no comprehensive opinion can be formed without the advantage of a testing program. Geologically, the no. 1 site is to be preferred, provided that the severe fracturing of the bedrock has not so increased the porosity and decreased the stability as to lose the advantage normally gained by a bedrock foundation. Considerable exploratory work will be required at all of these sites before a selection can be made.

Weminuche Pass—Transmountain Diversion

The project contemplates the diversion of two creeks, one on each side of the Los Pinos River at elevation 10,550, to the central stream near the head of the pass with a combined drainage area of 23 square miles and thence through the divide by means of a long cut. The canal discharges into an unnamed creek which flows into the Rio Grande Reservoir. Figure 129 is a general map of the plan. The routes of both canals were covered by strip topography taken with a planetable on a scale of 200 feet to the inch, with 5-foot contour interval.

Total run-off originating in the tributary watershed area was estimated by means of the altitude run-off curves used for the San Juan-Chama diversion project,

TABLE 15.—[illegible]

[illegible]	Quantity		[illegible]		Material furnished by [illegible]		Summary	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Total cost
[illegible]								
[illegible]	[illegible]	—	[illegible]	$1,000			[illegible]	[illegible]
[illegible]	[illegible]	Cubic yard	.75	300			.75	300
[illegible]	[illegible]	Cubic yard	3.00	1,200			3.00	1,200
[illegible]	[illegible]	Cubic yard	.25	25			.25	25
[illegible]	100	Cubic yard	.50	50			.50	50
[illegible]	[illegible]	Cubic yard	18.00	3,708	$3.75	[illegible]	21.75	4,481
[illegible]	5,200	[illegible]	.05	[illegible]	.10	520	.15	780
[illegible]	1,700	[illegible]	.05	[illegible]	.25	425	.30	510
[illegible]	21,000	[illegible]	.02	[illegible]	.035	735	.055	1,155
[illegible]	[illegible]	Cubic yard	1.50	383			1.50	383
[illegible]								
[illegible]	[illegible]	Cubic yard	.20	19,456			[illegible]	19,456
[illegible]	38,990	Cubic yard	.80	31,192			.80	31,192
[illegible]	100	Cubic yard	.25	[illegible]			.25	[illegible]
[illegible]	20,830	Square yard	.45	9,374			.45	[illegible]
[illegible]	[illegible]	Cubic yard	13.00	51,350	3.75	14,813	16.75	[illegible]
[illegible]	[illegible]	Pound	[illegible]	8,690	[illegible]	15,208	.055	[illegible]
[illegible]	75	Cubic yard	1.50	113			1.50	[illegible]
[illegible]	1.5	[illegible]	15,000.00	22,500			[illegible]	22,500
[illegible]	4.5	[illegible]	5,000.00	22,500			5,000.00	22,500
[illegible]				172,631		[illegible]		205,105
[illegible]								[illegible]
[illegible]								235,871
[illegible]								5,000
[illegible]								14,152
[illegible]								3,538
[illegible]								5,897
[illegible]								[illegible]

[1] Lump sum.

somewhat modified to more nearly fit the trend indicated by the records of the Pine River at Bayfield. The results for the years 1916–35 are presented in figure 130. Filings have been made and ditches practically completed for a total of 20 second-feet of water to be diverted from two small creeks within this area at elevations just high enough to be taken over the Weminuche divide without a deep cut, but no decrees have yet been secured. It is estimated, from a comparison of areas tributary to these ditches, that about 4,000 acre-feet, on the average, might be secured by such a diversion.

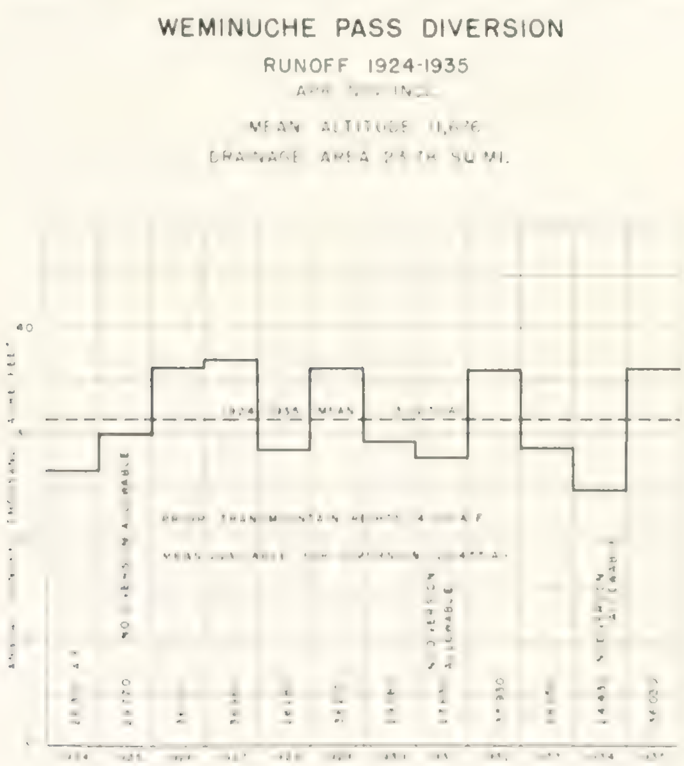


FIGURE 130

Diversions will be further limited in occasional years by the requirements for the Pine River project at Bayfield for which a reservoir of 125,000 acre-feet will soon be under construction to serve 69,000 acres of which about 35,000 acres are now being irrigated. A study of this project shows that while the reservoir would not have filled in 1925, 1931, and 1934, there would have been no serious shortages except in 1934.

The mean run-off from the intercepted area for 1924 to 1935 is estimated at 31,270 acre-feet. Allowing 4,000 acre-feet to care for prior rights for diversion through the pass and no water divertible in 1925, 1931, or 1934, by reason of the Pine River project demands, the 1924–35 average available for diversion is 20,455 acre-feet.

San Juan-South Fork Rio Grande Transmountain Diversion

General Plans

Early proposals for this diversion contemplated only a tunnel from Wolf Creek through the Continental

Divide to the South Fork of the Rio Grande, a collection system to divert the West Fork of the San Juan River into Beaver Creek, and both streams carried to the Wolf Creek portal by a ditch along the 9,000-foot contour. The terrain between Beaver Creek and Wolf Creek at this elevation is a succession of precipitous cliffs, close examination of which in the field disclosed the impracticability of such a plan.

The plan adopted (fig. 131) provides for the diversion of the West Fork of the San Juan River to Beaver Creek in a canal approximately 2 miles long, of which 2,400 feet is bench flume. From Beaver Creek an 8-foot tunnel, 3.2 miles long and of 425 second-feet capacity would carry water southeasterly to meet a tunnel of the same size and 1.1 miles long from Wolf Creek. A 9-foot tunnel, 6.7 miles long and of 525 second-feet capacity will lead from the junction to the South Fork of the Rio Grande.

It will require 7 miles of difficult road construction to gain access to the West Fork diversion and the Beaver Creek portal. The South Fork portal is within a half mile of the main graveled highway over Wolf Creek summit, which also passes within 200 feet of the Wolf Creek portal. The latter is approximately 15 miles from the Creede branch of the Denver & Rio Grande Western Railroad Co.

Concrete aggregates are expected to be secured within a few miles of the three tunnel portals.

Surveys

Triangulation of the tunnel lines was carried out from the Hot Springs site to Wolf Creek portal and then to the South Fork portal. Strip topography was taken from Hot Springs to Beaver Creek. The Hot Springs and Beaver Creek reservoir sites were surveyed on a scale of 200 feet to the inch and their damsites on a scale of 50 feet to the inch. Detailed topography was also taken at each of the tunnel portals.

Geology

Near the close of the Cretaceous period, the great Rocky Mountains were uplifted from the sea, marine deposition ceased, and in the San Juan region the early part of the following Tertiary period appears to have been one of comparative quiet with continuous erosion. Beginning with about Miocene time, a long series of eruptions progressively filled in the valleys and, in time, buried the highest peaks with lavas. During interspersed erosion periods, drainage patterns were developed, at times with deep canyons subsequently refilled.

The oldest formation which will be encountered in the tunnel is the Conejos andesite, a series of alternating andesites and related flows, containing breccias and agglomerate lenses of sand, gravel, and cobbles. Usually these lenses are well compacted with interstitial silts and clay, although a somewhat porous deposit is to be expected. Some lenses appear baked due to the heat of the overlying flows. This formation is about 800 feet thick where exposed as prominent cliffs near Beaver Creek.

Above the Conejos formation is a series of alternating flows and tuff beds called the Treasure Mountain quartz latites, mostly rhyolitic and latitic flows with minor amounts of breccias and agglomerates. The more massive members often stand out as bold vertical cliffs. In this locality the formation is about 1,200 feet thick.

Overlying the Treasure Mountain series is the Sheep Mountain formation, consisting of thin discontinuous flows and chaotic breccias. Many of the brecciated flows appear to have been hot enough when broken to have welded together again. Little foreign agglomeratic material is present. This series is about 800 feet thick near Beaver Creek, where it is exposed in prominent cliffs.

The Alboroto quartz latite overlies the Sheep Mountain series. It consists of an enormous thickness of tuff beds and thick regular flows of quartz latite. The tuff beds are indurated and in many ways are similar to the flows, some of which are many hundreds of feet thick and appear to be dense and massive, with no outstanding breaks or fractures. In this locality, the formation is at least 1,600 feet thick.

Overlying the Alboroto formation are the Huerto andesites, the youngest flows to be encountered in the tunnel, composed of thin discontinuous andesite flows, 20 to 80 feet thick, and chaotic masses of breccia. With the brecciated masses is much fine cementing material so that a fairly resistant deposit is formed.

As indicated on the geologic section (fig. 132), the Beaver Creek Portal will begin in the Alboroto quartz latite. About one-half mile from the portal on the far side of the fault, it may penetrate the Sheep Mountain andesite, raised above its normal position by drag folding along the fault. On penetrating the fault zone it will be in the Treasure Mountain quartz latite for nearly 6 miles, although some of the central portions may fall in the lower Conejos andesite series. The last 3 miles, near the South Fork portal, will be in the Alboroto formation. The short tunnel from Wolf Creek to the angle in the main tunnel will start in the upper part of the Conejos andesite and near the junction may enter the Treasure Mountain series. It is doubtful, however, whether in the tunnel the two formations can be differentiated.

Structurally, all the flows encountered will be approximately horizontal, but local variations will be


SAN JUAN - SOUTH FORK RIO GRANDE
TRANSMOUNTAIN DIVERSION
GENERAL MAP
253-D-68
WOLF CREEK
WATERSHED AREA
BEAVER CREEK
WATERSHED AREA
WEST FORK - SAN JUAN
WATERSHED AREA
TUNNEL SECTION
TUNNEL SECTION
EARTH SECTION
BENCH FLUME
HYDRAULIC PROPERTIES

SAN JUAN – SOUTH FORK RIO GRANDE DIVERSION TUNNEL

Figure 132

found with radical changes in the vicinity of the Beaver Creek fault. The only large fault indicated by present preliminary investigation will be penetrated by the tunnel not far from the present Beaver Creek portal. This is a large fault with a known vertical displacement of over 2,000 feet. It is entirely possible, but not expected, that other less severe displacements will be encountered. The faults seem now inactive.

Contacts between flows undoubtedly will contain local gravel or other detritus remnants incorporated between successive flows. As a generalization, these lensed inclusions may be more extensive between formation contacts than between intraformational flows. Such zones may cause soft caving ground.

It is probable that the regional water table is extremely erratic due to the variable permeabilities of the flow members and the repeated changes in the drainage pattern. Some areas are likely to show water close to the surface while others will be dry for possibly thousands of feet. The area has, however, a high runoff and the total supply is great so that any opportunity to build up a high table would be taken. Under such a high table, if the tunnel happens to tap a fractured zone or other porous structure, the inflow may be great and of long duration. Areas that are open to the most suspicion are those in the Treasure Mountain and Conejos formations as well as in the fault zone. The Alboroto latites are, in general, massive and relatively impervious. Insofar as there is no regional under lying impervious basement as at the Silverton tunnel, large ground water basins will probably be rare and of local extent.

The tunnels will be in rock throughout but a section not far from the Rio Grande portal passes beneath a basin under which the rock cover will not be great.

It is believed that, on the whole, the rock will be adequately competent to support itself. Even the agglomerate lenses, where exposed, appear quite solid. Construction should be preceded by additional surveys, supplemented by some drilling.

Beaver Creek Reservoir and Dam Site

The bedrock in the basin is made up of a wide variety of volcanic materials, ranging from flows, agglomerates, and breccias to tuff. The complexity of the relationships is due to a fault running up and down the valley, a continuation of that penetrated by the tunnel.

The basin is, in general, heavily mantled with overburden materials, the bottom with river sorted gravels and sand, while talus and outwash materials cover the valley sides with varying thickness.

The reservoir basin has a normal tributary water table as indicated by spring and seep occurrences.

The ultimate bedrock at the dam site is probably the Huerto andesite, a volcanic flow formation, including

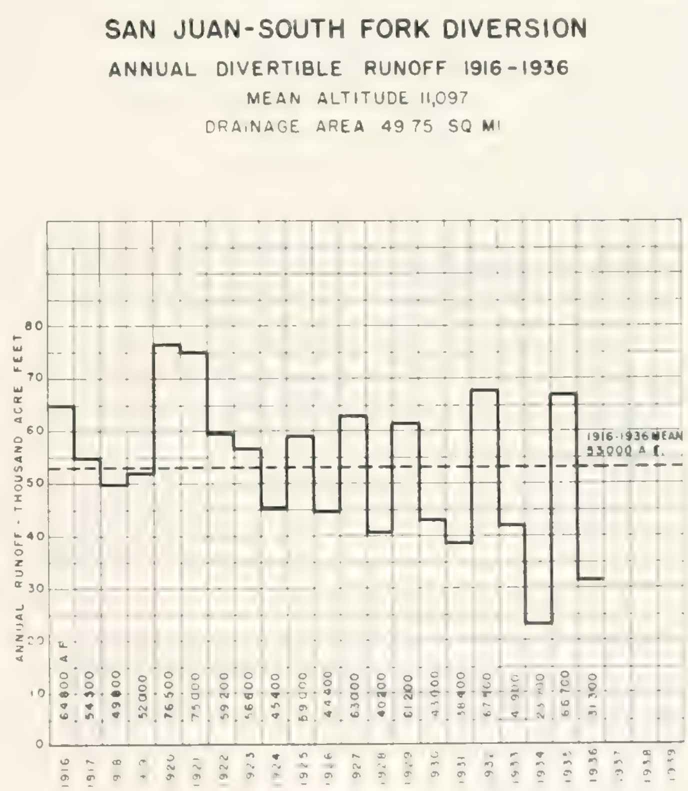


Figure 133

volcanic breccias and agglomerates. A fault passes up and downstream through the foundation, bringing older Potosi volcanics in juxtaposition to the above-mentioned Huerto andesite. Bedrock will not be economically within reach for either foundation or abutments.

The right abutment consists of slump rock and soil slowly creeping toward the stream bed. For 800 feet vertically above the bottom of the valley, one can see hundreds of irregularly tilted blocks of shattered rock. Near the proposed axis the slope of this creep material is 40° or more, indicating that the material will continue to move when conditions are favorable. The depth of this deposit is unknown with estimates ranging from 20 to 100 feet.

From a gully adjacent to the left abutment, torrential floods have washed large quantities of rock and soil to form an outwash fan of unknown depth. This deposit of debris was progressively built up faster than the main stream could carry it away, resulting in a choking of the valley to form the present reservoir basin. The choking of the stream has been an intermittent affair so that the central portions of the dam may be underlain with alternate wash and areas of more or less stratified deposits.

Perhaps the most serious problem concerns the ability of the overburdens to take the dam load and meet the permeability requirements. Nothing can be concluded in this regard without a complete test pit program. Another feature is the right abutment slide area probably still in motion down the slope. A third feature is possible leakage through the fault and the fractured bedrock. A drill program should ascertain the rock profile, the condition of the bedrock, and its porosity. No recent movement is indicated along this fault line.

Hot Springs Reservoir and Dam Site

The reservoir basin is believed competent with a water table tributary to the stream. The valley is cut in the massive Alboroto quartz latite volcanic flows, little fractured. The sides of the valley are often bare but some areas are covered with a thin wash of soil and large angular rock. The basin is filled with similar material.

The river is flowing on bedrock and the abutments are for the most part bare. The flatter slopes back from the canyon edge are covered by a thin veneer (possibly 10 to 20 feet) of wash, composed of rock fragments embedded in some silt.

The rock on which the dam will rest is the Alboroto quartz latite, a series of thick massive flows and tuff beds. The flows are essentially horizontal, dipping only a few degrees to the north, without apparent faulting or fissuring. Minor grouting may be required.

Several hot springs issue from isolated joints in the rock, suggesting at least some deep water circulation possibly related to the Beaver Creek fault which, however, is located well out of the immediate dam area.

TABLE 14.—*San Juan-South Fork Rio Grande transmountain diversion estimate*

[illegible]	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
[illegible] West Fork, Beaver Creek, Wolf Creek								
[illegible]	[illegible]	[illegible]	$500.00	$1,500			[illegible]	$1,500
[illegible]	[illegible]	Cubic yard	.75	225			.75	[illegible]
[illegible]	[illegible]	Cubic yard	3.00	2,850			3.00	2,850
[illegible]	250	Cubic yard	.25	[illegible]			.25	[illegible]
[illegible]	[illegible]	Cubic yard	.50	125			[illegible]	[illegible]
[illegible]	[illegible]	Cubic yard	18.00	6,930	$3.75	$1,444	21.75	8,374
[illegible]	34,000	Pound	.02	[illegible]	.035	1,190	.055	[illegible]
[illegible]	[illegible]	Cubic yard	1.50	300			1.50	300
[illegible]								
[illegible]	[illegible]	Cubic yard	.25	11,425			.25	[illegible]
[illegible]	[illegible]	Cubic yard	.80	49,440			.80	49,440
[illegible]	985	Cubic yard	18.00	17,730	3.75	3,694	21.75	21,424
[illegible]	88,700	Pound	.02	1,774	.035	3,105	.055	4,879
[illegible]								
[illegible]	190,000	Cubic yard	14.00	2,660,000			14.00	2,660,000
[illegible]	[illegible]	[illegible]	.08	51,040			.08	51,040
[illegible]	[illegible]	[illegible]	80.00	42,640			80.00	42,640
[illegible]	47,800	[illegible]	15.00	717,000	5.00	239,000	20.00	956,000
[illegible]	1,775,000	[illegible]	.08	142,000			[illegible]	142,000
[illegible]	46,000	[illegible]	1.50	69,000	[illegible]	46,000	2.50	[illegible]
[illegible]	[illegible]	[illegible]	15,000.00	105,000			15,000.00	105,000
[illegible]				[illegible]		[illegible]		4,174,155
[illegible]								[illegible]
[illegible]								[illegible]
[illegible]								[illegible]
[illegible]								288,017
[illegible]								72,004
[illegible]								120,007
[illegible]								[illegible]

[illegible]

Water Supply

Areas and mean altitudes of each individual area above the diversion point for the several plans considered were measured and run-off calculated from the altitude run-off curves already developed for the San Juan-Chama Diversion.

A reservoir at the Beaver Creek site of 4,500 acre-feet capacity requires a dam 100 feet high and 1,100 feet long with foundation conditions apparently very poor, although no explorations were made.

Above the diversion from the West Fork of the San Juan River, the Hot Springs Reservoir, with a capacity of 3,400 acre-feet, would require a dam 650 feet long and of 130 feet maximum height, with a cost roughly estimated at $1,000,000.

The reduction in canal and tunnel capacities, together with the small increase in water supply which these regulatory reservoirs would accomplish, is not commensurate with their cost. They are, therefore, omitted from the plan presented. The waters estimated to be divertible average 53,000 acre-feet annually, as shown on figure 133.

Conejos River Storage

The original program of investigation on the Conejos River contemplated only the drilling, prospecting, surveying, and estimate designs for a dam at site no. 1. This site had been previously investigated under the auspices of an association of water users on the Conejos River, but no foundation exploration had been done.

Conditions disclosed by initial drilling raised questions as to its feasibility. After consultation with interested parties, the scope of the investigation was broadened to include the prospecting, surveying, and estimate designs for other sites.

The location of all sites investigated is shown on figure 134. The extent of investigations at each is as follows:

Lower river

Dam site	Extent of investigations
Site no. 1	Six drill holes, two test pits, one drift, dam site survey. Rough estimate and design. Tipton Reservoir survey utilized.
Site no. 2	One drill hole in river bottom. Tipton Reservoir survey extended from no. 1.
Elk Creek site	Reconnaissance only.
Site no. 3	One drill hole on river bottom. No surveys. Geological reconnaissance.
Granite site	One drill hole, dam, and reservoir survey. Geological reconnaissance. Rough design and estimate.
Fox Creek site	Geological reconnaissance only.
Mogote site	One drill hole, three test pits, laboratory analysis of material. Dam, reservoir, and feeder canal surveys, estimates, and design.

Upper river

Site no. 4	One drill hole. Geological reconnaissance. No surveys.
Site no. 5	Three drill holes, dam site survey, geological reconnaissance.
Site no. 6	Reservoir and dam site survey. Geological examination. Design and estimates.

Dam Site No. 1 [2]

The reservoir is an erosional basin carved into a rock sequence of andesite flows, flow breccia, and agglomerate, dipping slightly downstream (1°–3°). In places erosion has penetrated to the granite floor on which the volcanics were extruded. Below the flow line, the sides of the basin are erratically covered with terrace gravels, wash, slump, and landslide materials. The water table is tributary to the stream as evidenced by normal ground water springs and seeps. This, together with consideration of the bedrock character, suggests that no significant seepage from the reservoir itself is to be expected.

The dam site is a narrows in which the enclosing bedrock is the same andesite complex found throughout the reservoir and no structural disturbances of folding or faulting were observed. The controlling factors to dam design are found not in the rock but in the character and relations of the various detrital overburdens. The right abutment is landslide debris, a heterogeneous aggregate of angular boulders, fragments, and crushed rock, together with some infiltrated surface silts. One drill hole and test pit indicates that the material is quite erratic both in composition and permeability. The slide debris is over 150 feet deep and rests on porous river gravels. It is believed that under present conditions the slide is quite stable, but this may not hold under the conditions imposed by the reservoir. The left abutment, as indicated by three drill holes, shows a narrow ridge of andesite extending to the river but flanked on both sides by deep wash and slump materials overlying terrace and river gravels. The ridge-like character of this abutment suggested that the rock is not in place but this suspicion was not upheld by one drill hole which penetrated rock for a depth of 146 feet. Drill holes show stratified river gravels or a loose, porous assemblage of gravel, cobbles, sand, and occasional boulders to be up to 200 feet deep in the river channel and they may be equally deep under the landslide and under the wash and slump deposits on the left slope. These gravels once extended higher than they do today, as evidenced by terrace remnants found 50 feet above the river. The landslide occurred over these gravels, when they were at river level, showing that the movement was not of recent occurrence.

[2] Figs. 135b and 136.


CONEJOS RIVER WATERSHED
DAM AND RESERVOIR SITES
WATERSHED BOUNDARY
COLORADO
NEW MEXICO
GRANITE SITE

Design and estimates. The unfavorable foundation conditions demand extreme conservatism in the design of the dam. Construction of a cut-off to prevent percolation through the foundation is impractical. Reliance for safety must then be placed upon flat slopes, upstream blanketing and loose rock backing on the lower slope. Water losses beneath the dam may be estimated only after intensive and costly permeability investigations have been made. The results thereof may necessitate measures for control of percolation beyond those contemplated in the tentative design.

A dam 140 feet high to store 100,000 acre-feet is roughly estimated to cost $3,700,000.

Dam Site No. 2

This site was considered as a possible alternative to no. 1 dam site. Preliminary investigation did not indicate such superior merit as to warrant unequivocal acceptance. The reservoir basin is the same as that commanded by the no. 1 site and no new factors are introduced.

The dam site geology is in many ways parallel to the conditions found at the upper site. The bedrock is a complex of Conejos andesite, flow breccia, and agglomerate dipping downstream (1°–3°) and no faulting is in evidence. As at the no. 1 site, the most important factors involve the condition and relations of the various overburdens. The left abutment is a landslide of uncertain origin, composed of angular boulders, fragments, and crushed rock with much infiltrated surface silts. It overlies river gravels which will be found to extend to considerable depth, possibly 100–150 feet. The right abutment shows bedrock close to the surface but conditions immediately up and down stream from the axis have not been determined. One hole, drilled to a depth of 90 feet, was entirely in river gravels which, in all probability, continue to over 150 feet. As at the upper site, terrace gravels, erratic wash, and talus deposits are found at various positions on the abutments.

The geological problems involve permeability of the left abutment slide and the underlying foundation. The stability of the landslide debris is open to question with regard to piping, settlement, or other transfer of material. As the site is geologically no better than the no. 1 site, with the dam more costly, it has been given no further consideration.

Elk Creek Site

This dam site, utilizing the Elk Creek storage basin, is located about 2 miles upstream from site no. 1. The dam must necessarily be a large one and, because of this, has not heretofore been seriously considered. Perhaps the main advantage of this site is the absence of landslide abutments giving access to the deep foundation gravels.

The dam site has by no means ideal geological conditions, but the simple relationships have not been altered by landslide or other structural disturbances. Both abutments are composed of Conejos andesite, flow breccia, and agglomerate, dipping 2° to 3° downstream. All rock is believed to be in place but is covered with various amounts of wash and talus interfingering with the bottom river gravels. The foundation gravels may prove to be 150 feet or more in depth.

Construction problems have to deal mainly with the control of foundation percolation.

Neglecting the excessive size of the required dam, this site is geologically preferable to the Conejos no. 1 or 2 sites.

Dam Site No. 3

The reservoir utilizes the South Fork Basin and is probably the highest site on the river which can control South Fork run-off. Like no. 1 reservoir, the valley is an erosional basin in the Conejos andesite, flow breccia, and agglomerate complex, heavily mantled with detrital overburdens below the flow line. The bottom flats are covered with deep porous gravels and the sides with erratic landslide, wash, slump, and terrace deposits. The water table is tributary to the stream and no reservoir seepage is to be expected.

The dam site has many unattractive features. Rock will be deep in the foundation and abutments. Both abutments are of landslide material, composed largely of angular rock and rock fragments with some interstitial silts. One drill hole in the foundation penetrated boulders, gravel, and sand to a depth of 172 feet without reaching bedrock.

While the river bed gravels are quite permeable, they would be stable under earth-dam conditions. The slide materials on the other hand may be both permeable and unstable. The large volume of any dam constructed at this site, together wlth the unattractive foundation conditions, were responsible for the limited consideration given to this site.

Fox Creek Site

The San Juan Peneplain, comprising impervious andesitic flows, was here eroded to a flat surface lying well above the reservoir area on the right but dipping with a slope of 2 to 3° below the reservoir level in the left side. This original flat surface was covered with gravels and silts and topped with a thin flow of basalt (Los Pinos and Hinsdale formations). On tilting, stream erosion began progressively to strip off these less competent deposits, so that now the left rim of the reservoir has a retaining wall or hogback of compacted silts and gravel

CONEJOS DAM SITE No 5

with a basalt cap. The water table is above the andesite on the right side. Ground waters probably flow down the dipping andesite on the left side to form an artesian flow in the main San Luis Valley. Under such conditions the reservoir seepage may prove to be large.

At the dam site the right abutment is of hard, impervious andesite overlain by erratic detrital talus and wash. The left end of the dam would rest on the northeast dipping, compacted silts, gravel and upper basalt, through which the water table falls. A block slide on this abutment has displaced a section of the capping basalts, lowering it to the present river level. Downstream from the axis this slide was disrupted to give rise to a landslide. The foundation along the axis is mantled with a depth of possibly 150 to 200 feet of recent, porous, stream gravels, cobbles, and sand.

The block slide, forming the left abutment, is shattered and instability is indicated by the present steep slopes and the soft character of the underlying materials. The deep foundation gravels are themselves quite permeable and probably feed directly to an underlying artesian member.

In view of the unfavorable geological conditions and the difficult remedial measures required, further consideration was deferred pending consideration of other, geologically more feasible, sites.

Granite Dam Site [2a]

Reservoir conditions are similar to no. 1 site and no lateral seepage is to be expected. Granite bedrock is exposed in the present stream channel.

The most important feature at the dam site is the probability of a deeper stream gorge under the right abutment terrace. Drill hole no. 1 encountered the granite bedrock 30 feet below the present stream bed. Bedrock may prove to be well over 100 feet below the present river level, along the center of such a buried channel, the profile and location of which have not been determined. Overlying the bedrock are stratified sand, gravel, and boulders, which are remnants of terraces.

On the left abutment the granite is overlain by a series of agglomerate and ash, in turn covered by andesite flows and flow breccias. The ash layers appear quite compact. Normal talus debris mantles the abutment, increasing in depth from 5 to 25 feet up the slope. Permeability of the right abutment materials and the character of the left abutment contacts and ashes are important factors deserving further study if the site is to be seriously considered.

Storage capacity of 100,000 acre-feet at this site will require a dam with 210 feet maximum height and a crest length of 3,000 feet. Its cost is roughly estimated at $3,655,000.

[2a] Fig. 135c.

Dam Site No. 4

This site is located in a narrows below Fisher Gulch about 3½ miles below Platoro, Colo. Only a short geological reconnaissance was completed but the rock and overburden conditions have not proven satisfactory.

A high dam would given considerable storage but would flood numerous mining claims.

The reservoir basin involves many geological structures. Several faults cross the valley. The bottom flats are covered with river gravels and the flanks of the basin are erratically covered with landslide, talus, wash, terrace, and other detrital deposits. The ground water is tributary to the stream so that reservoir conditions can be considered satisfactory.

At the dam site, bedrock is the Conejos andesite formation of andesitic flows, flow breccias, ashes, and agglomerates, which on the right abutment dip steeply to the northeast (strike N. 40 W., dip 80 NE.). The dip on the left abutment is much flatter. The steep dip on the right abutment is probably due to a large fault running parallel to the river in the vicinity of Lake Fork. The left abutment shows a relatively thick mantle of talus rubble, overriding bottom terrace and recent gravels of unknown depth. The underlying rock may be quite shattered. The right abutment, on the other hand, is composed entirely of slump and landslide materials, showing much fine silty matrix so that it appears remarkably compact. One drill hole was churned to 75 feet without encountering bedrock.

The 1912–35 mean annual run-off at this site was estimated at 55,000 acre-feet, of which not over 35,000 acre-feet could be stored without inteference with prior rights. Reconnaissance indicated that a dam more than 100 feet in maximum height and a crest length of about 1,000 feet would be required to store the available quantity. Its cost per acre-foot would greatly exceed the cost of no. 6 site. This fact, together with the more favorable geological conditions at no. 6 site, led to abandonment of explorations at an early stage.

Dam Site No. 5 [3]

Conejos dam site no. 5 is about 1 mile below Platoro, in the same reservoir basin controlled by the no. 4 site, but at the head of the steeper section. The site is attractive for a small dam (50 to 60 ft.).

The reservoir basin is eroded from a massive, horizontal, andesite flow, characteristic of this area. Much of the rock is severely fractured and igneous intrusive dikes as well as mineralized zones are common. The bottom is mantled with river gravels and the sides are erratically flanked with terrace gravels, wash, or talus deposits. Ground water is tributary to the stream and no reservoir loss is expected.

[3] Fig. 1[illegible].

CONEJOS DAM SITE No I

[illegible]

The dam site utilizes a narrows where a low andesite ridge crosses the basin. This ridge is apparently due to superior erosional resistance. All the rock is rather severely fractured but as evidenced by pressure tests in two drill holes, these planes are tight at depth and should allow little seepage. These fractures tend to localize in erratic shear zones. The site is quite free of detrital deposits with but 20 feet of gravels found in the river channel. A wedge of porous terrace gravel lies on the right abutment, which together with all such detrital materials, should be entirely excavated. Pockets of the same gravel may be found in the depressions along the ridge. Considerable blocky talus will be encountered against the left abutment face.

Construction problems vary largely with the size of the contemplated dam. A 50-foot structure will have small economical dam section, while a higher structure must include dikes along the rock ridge.

The low dam would provide in sufficient storage capacity; the higher would be expensive. The site was, therefore, abandoned in favor of no. 6 site.

No. 6 Site

The dam site is located about a mile upstream from Platoro which is 42.5 miles by gravelled highway from Monte Vista, the nearest railroad shipping point. The reservoir is entirely on Government land within a United States forest reserve.

Summary of data:

Storage capacity	32,000 acre-feet.
Spillway capacity	6,000 second-feet.
Outlet capacity (1,000 acre-foot level)	500 second-feet.
Elevation top of parapet	10,013.
Elevation top of dam	10,010.
Elevation of spillway crest	10,000.
Maximum water-surface	10,005.
Reservoir area at spillway level	710 acres.
Maximum height of dam	115 feet.
Estimated cost—dam and reservoir	$608,000.
Reservoir topography	Fig. 137.
General plan and sections	Fig. 138.
Preliminary estimate	Table 15.

Geology.—In many ways this site is geologically one of the most favorable sites to be found on the Conejos River. The reservoir basin is cut into a rock complex of massive andesite flows and flow breccias with numerous intruded sills and dikes. Two major faults cross the basin which are probably related in age to the severe fracturing of all the regional rock, a common feature in this area. The sides of the basin are erratically mantled with talus and wash, which interfingers with the bottom gravel deposits. The water table is tributary to the stream and no reservoir seepage loss is expected.

The dam site is in a canyon narrows eroded into a thick, massive andesite flow dipping slightly downstream. Detrital deposits are shallow on the abutments and foundation. All the rock is excessively fractured and localized shear zones are common. One of these is along the location of the diversion tunnel and spillway so that excavation may prove somewhat difficult

No drilling or test pits were considered necessary for preliminary designs, but extensive drilling will ultimately be required for the purpose of more closely determining the scope of grouting and stripping operations.

Dam.—Owing to the long haul for cement and the close proximity of sufficient embankment materials, this site appears to be best suited for the compacted embankment type of dam. It is estimated that there is sufficient material about three-fourths of a mile upstream from the site for embankment borrow quantities. There are ample sand and gravel deposits along the river within one-half mile upstream for the limited amount of concrete necessary for this dam.

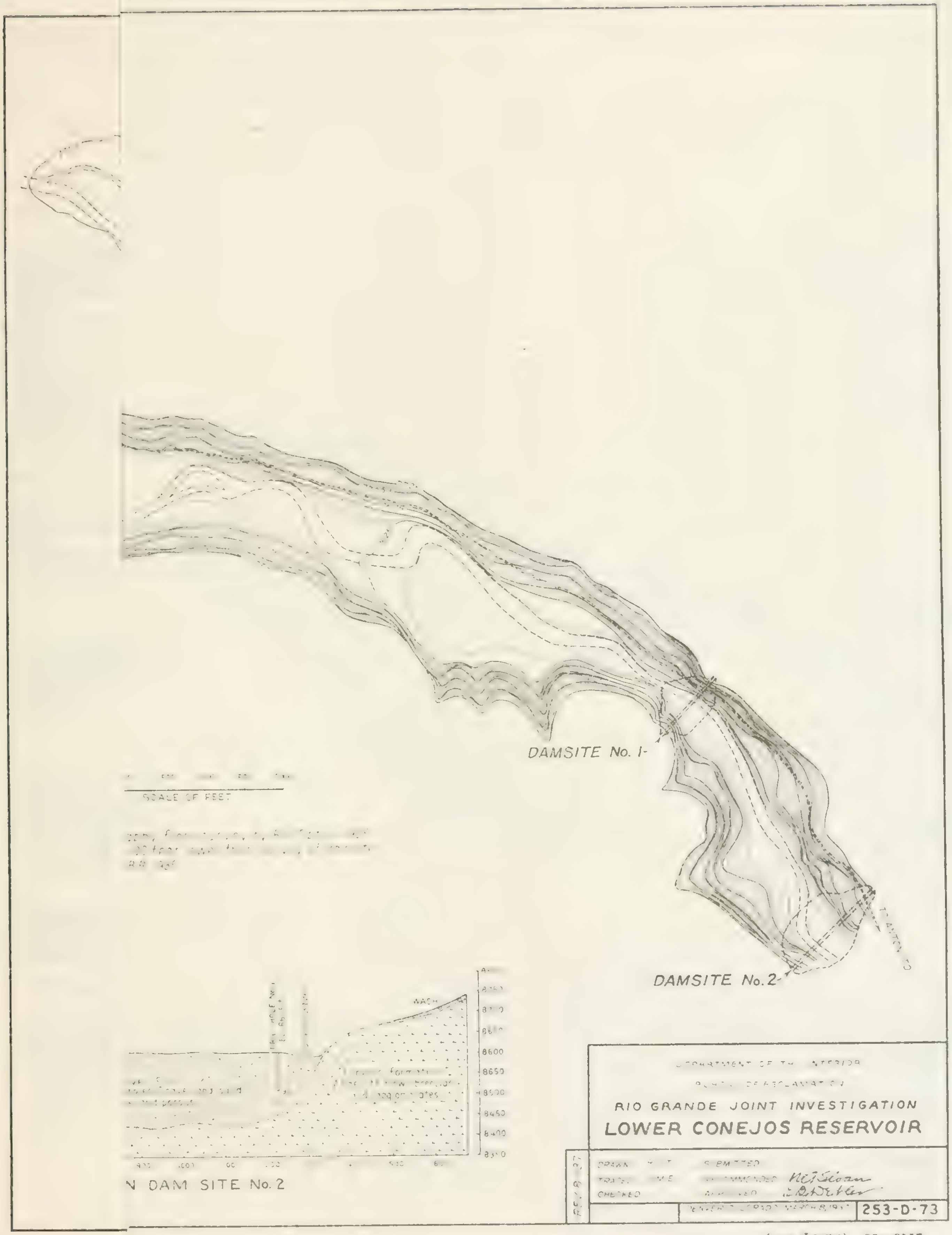
Figure 138 shows the general plan and sections of the proposed dam and dike. The main dam is 540 feet long at the crest and attains a maximum height of 115 feet. The dike, some 400 feet to the left of the dam, is 400 feet long with a height of 38 feet. The typical embankment section has a 35-foot top width at elevation 10,010, a graveled roadway, and typical concrete parapets and curbs. The upstream slope is 3:1 with a 12-inch gravel blanket overlain by 3 feet of rock riprap. The downstream slope is 2½:1 with 2 feet of dumped rock for weather protection. It will be necessary to strip the vegetation from the site downstream from the axis and all of the material overlying the rock upstream from the axis. A considerable amount of this excavation can be used in the downstream portion of the embankment. Excavation is assumed to average 10 feet for the lower portions of the dam and 15 feet for the dike. The cofferdam is designed to be bulldozed back against the toe of the dam on a 5:1 slope. A concrete cutoff wall extends the entire length of the dam and dike.

Spillway.—A gate-operated spillway is inadvisable under the adverse climatic conditions and a side channel uncontrolled crest spillway was adopted. This spillway crest is 140 feet long and at elevation 10,000 discharges 6,000 second-feet with 5 feet of water over the crest. This spillway will be constructed entirely in sound rock and concrete-lined throughout. A concrete arch bridge will span the spillway channel.

Outlet works.—An 8.5-foot horseshoe concrete-lined tunnel will serve the purposes of river diversion during construction and later as an outlet. With the cofferdam constructed to elevation 9935 and the water surface at 9930 or 5 feet below the crest of the cofferdam, the tunnel will discharge 2,000 second-feet. After diversion one 72-inch diameter ring follower emergency gate and one 66-inch needle valve will be installed in the gate

GRANITE DAM SITE

Figure [illegible]


DAMSITE No. 1
DAMSITE No. 2
SCALE OF FEET
N DAM SITE No. 2
RIO GRANDE JOINT INVESTIGATION
LOWER CONEJOS RESERVOIR
253-D-73

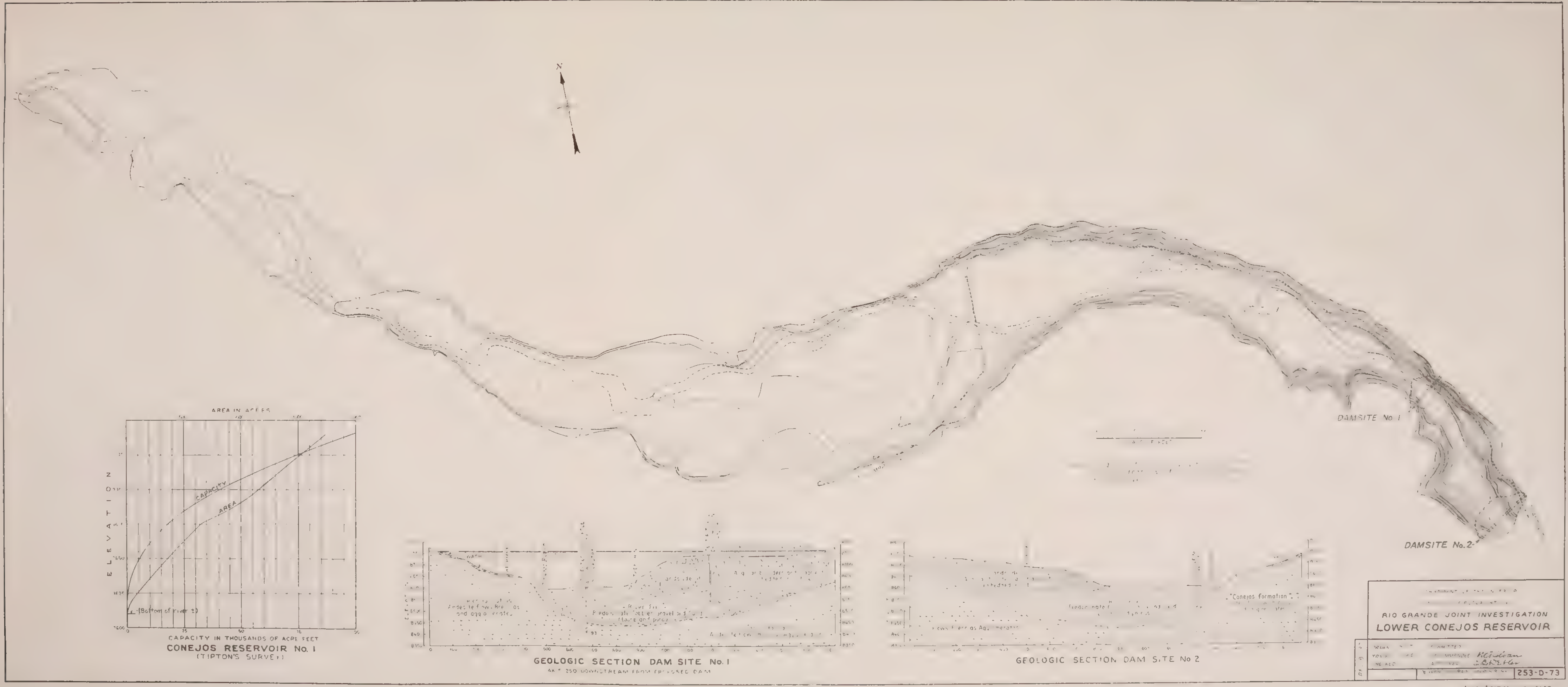

N
DAMSITE No. 1
DAMSITE No. 2
AREA IN ACRES
ELEVATION
CAPACITY
AREA
Bottom of river
CAPACITY IN THOUSANDS OF ACRE FEET
CONEJOS RESERVOIR No. 1
(TIPTON'S SURVEY)
GEOLOGIC SECTION DAM SITE No. 1
GEOLOGIC SECTION DAM SITE No 2
"Conejos formation"
RIO GRANDE JOINT INVESTIGATION
LOWER CONEJOS RESERVOIR
253-D-73

Figure 136

TABLE 15.—*Upper Conejos Dam, preliminary estimate, Jan. 30, [illegible]*

[Earth embankment: top of dam elevation 10,010, normal water surface elevation 10,000, maximum water surface elevation [illegible]; maximum height of dam, [illegible] feet; drawing [illegible] 253-D-76]

[Storage capacity, 32,000 acre-feet; spillway capacity, 6,000 second-feet; diversion capacity, 2,000 second-feet; required outlet capacity, 500 second-feet]

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
RIVER WORK								
Diversion, and unwatering foundations	(1)	(1)	(1)	$3,000			(1)	$3,000
EARTHWORK								
Excavation, common:								
Stripping, dam foundation	15,300	Cubic yard	$0.30	4,590			$0.30	4,590
Stripping, borrow pits	40,000	Cubic yard	.30	12,000			.30	12,000
Dam foundation	22,255	Cubic yard	.30	6,677			.30	6,677
Toe drains and cut-off trenches	355	Cubic yard	.40	142			.40	142
Spillway, and tunnel inlet and outlet	1,000	Cubic yard	.40	400			.40	400
Roadway	1,830	Cubic yard	.35	641			.35	641
Borrow, and transportation to dam	353,100	Cubic yard	.30	105,930			.30	105,930
Excavation, rock:								
Cut-off wall	220	Cubic yard	4.00	880			4.00	880
Spillway, and tunnel inlet and outlet	28,700	Cubic yard	2.50	71,750			2.50	71,750
Roadway	3,670	Cubic yard	2.00	7,340			2.00	7,340
Outlet tunnel and shaft	3,400	Cubic yard	10.00	34,000			10.00	34,000
Embankment:								
Earth fill compacted	328,300	Cubic yard	.10	32,830			.10	32,830
Dumped rock on downstream slope	6,610	Cubic yard	.30	1,983			.30	1,983
Riprap rock on upstream slope	13,690	Cubic yard	.40	5,476			.40	5,476
Backfill about structures	1,100	Cubic yard	.50	550			.50	550
Gravel for roadway and spillway	1,900	Cubic yard	1.50	2,850			1.50	2,850
GROUTING AND DRAINAGE								
Drilling:								
Grout holes not over 25 feet deep	6,000	Linear foot	1.00	6,000			1.00	6,000
Drain holes	1,400	Linear foot	1.00	1,400			1.00	1,400
Weep holes	350	Linear foot	1.00	350			1.00	350
Anchor bars and grouting in place	2,700	Linear foot	1.00	2,700	$0.10	$270	1.10	2,970
Pressure grouting: Foundation	15,000	Cubic foot	1.10	16,500	.90	13,500	2.00	30,000
Drain tile:								
12-inch diameter clay tile in gravel	325	Linear foot	.70	228	.45	146	1.15	374
8-inch diameter clay tile in gravel	775	Linear foot	.60	465	.30	233	.90	698
6-inch diameter clay tile in gravel	600	Linear foot	.50	300	.20	120	.70	420
4-inch split tile for spillway	300	Linear foot	.40	120	.15	45	.55	165
CONCRETE WORK								
Concrete:								
Cut-off wall not formed	220	Cubic yard	10.00	2,200	3.60	792	13.60	2,992
Cut-off wall formed	450	Cubic yard	12.00	5,400	4.00	1,800	16.00	7,200
Parapets and curb walls	370	Cubic yard	20.00	7,400	4.00	1,480	24.00	8,880
Trash rack and transition	125	Cubic yard	15.00	1,875	4.00	500	19.00	2,375
Below operating floor of gate chamber	175	Cubic yard	12.00	2,100	3.60	630	15.60	2,730
Tunnel, shaft, and gate chamber	1,100	Cubic yard	14.00	15,400	3.60	3,960	17.60	19,360
Spillway	1,950	Cubic yard	11.00	21,450	3.60	7,020	14.60	28,470
Control house	20	Cubic yard	20.00	400	4.00	80	24.00	480
Spillway bridge	200	Cubic yard	15.00	3,000	4.00	800	19.00	3,800
METALWORK								
Metal:								
Trash rack	25,000	Pound	.02	500	.08	2,000	.10	2,500
Reinforcement steel	284,000	Pound	.02	5,680	.03	8,520	.05	14,200
Spiral stairway	17,500	Pound	.03	525	.11	1,925	.14	2,450
Water stops	400	Linear foot	.30	120	.40	160	.70	280
72-inch ring-follower gate and control mechanism	51,000	Pound	.04	2,040	.24	12,240	.28	14,280
60-inch needle valve and control mechanism	58,000	Pound	.03	1,740	.22	12,760	.25	14,500
12-ton hand hoist	35,000	Pound	.02	700	.19	6,650	.21	7,350
Gas-electric generator set and equipment	(1)	(1)	(1)	200	(1)	800	(1)	1,000
Miscellaneous metalwork	2,000	Pound	.10	200	.10	200	.20	400
Grout and drain pipe	5,300	Pound	.05	265	.07	371	.12	636
MISCELLANEOUS ITEMS								
Items:								
Control house except concrete	(1)	(1)		200		800	(1)	1,000
Transporting freight, except cement, for Government from Monte Vista, Colo., to the dam site (43.5 miles)	250	Ton	4.80	1,200				1,200
Highway construction	1	Mile		5,000				5,000
Clearing reservoir	100	Acre	25.00	2,500			25.00	2,500
Subtotal				399,197		77,802		476,999
Contingencies, 15 percent								71,550
Total estimated field cost								548,549
Investigations and surveys	(1)						(1)	5,000
Engineering and inspection, 6 percent								32,913
Superintendence and accounts, 1½ percent								8,228
General expense, 2½ percent								13,714
Total estimated cost								608,404
Cost per acre-foot storage								19.01

[1] Lump sum.

TABLE 15.—*Upper Conejos Dam, preliminary estimate, Jan. 30, 1937*

[Earth embankment; top of dam elevation 10,01[illegible], normal water-surface elevation [illegible] [illegible]]

[Storage capacity, 32,000 acre-feet; spillway capacity, 6,000 second-feet; diversion capacity, 2,000 second-feet; required outlet capacity, 500 second-feet]

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
RIVER WORK								
Diversion, and unwatering foundations	(1)	(1)	(1)	$3,000			(1)	$3,000
EARTHWORK								
Excavation, common:								
Stripping dam foundation	15,300	Cubic yard	$0.30	4,590			$0.30	4,590
Stripping borrow pits	40,000	Cubic yard	.30	12,000			.30	12,000
Dam foundation	22,255	Cubic yard	.30	6,677			.30	[illegible]
Toe drains and cut-off trenches	355	Cubic yard	.40	142			.40	142
Spillway, and tunnel inlet and outlet	1,000	Cubic yard	.40	400			.40	400
Roadway	1,830	Cubic yard	.35	641			.35	641
Borrow, and transportation to dam	353,100	Cubic yard	.30	105,930			.30	105,930
Excavation, rock:								
Cut-off wall	220	Cubic yard	4.00	880			4.00	880
Spillway, and tunnel inlet and outlet	28,700	Cubic yard	2.50	71,750			2.50	71,750
Roadway	3,670	Cubic yard	2.00	7,340			2.00	7,340
Outlet tunnel and shaft	3,400	Cubic yard	10.00	34,000			10.00	34,000
Embankment:								
Earth fill compacted	328,300	Cubic yard	.10	32,830			.10	32,830
Dumped rock on downstream slope	6,610	Cubic yard	.30	1,983			.30	1,983
Riprap rock on upstream slope	13,690	Cubic yard	.40	5,476			.40	5,476
Backfill about structures	1,100	Cubic yard	.50	550			.50	550
Gravel for roadway and spillway	1,900	Cubic yard	1.50	2,850			1.50	2,850
GROUTING AND DRAINAGE								
Drilling:								
Grout holes not over 2[illegible] feet deep	6,000	Linear foot	1.00	6,000			1.00	6,000
Drain holes	1,400	Linear foot	1.00	1,400			1.00	1,400
Weep holes	350	Linear foot	1.00	350			1.00	[illegible]
Anchor bars and grouting in place	2,700	Linear foot	1.00	2,700	$0.10	$270	1.10	2,970
Pressure grouting foundation	15,000	Cubic foot	1.10	16,500	.90	13,500	2.00	30,000
Drain tile:								
12-inch diameter clay tile in gravel	325	Linear foot	.70	228	.45	146	1.15	374
8-inch diameter clay tile in gravel	775	Linear foot	.60	465	.30	233	.90	698
6-inch diameter clay tile in gravel	600	Linear foot	.50	300	.20	120	.70	420
4-inch split tile for spillway	300	Linear foot	.40	120	.15	45	.55	165
CONCRETE WORK								
Concrete:								
Cut-off wall not formed	220	Cubic yard	10.00	2,200	3.60	792	13.60	2,992
Cut-off wall formed	450	Cubic yard	12.00	5,400	4.00	1,800	16.00	7,200
Parapets and curb walls	370	Cubic yard	20.00	7,400	4.00	1,480	24.00	8,880
Trash rack and transition	125	Cubic yard	15.00	1,875	4.00	500	19.00	2,375
Below operating floor of gate chamber	175	Cubic yard	12.00	2,100	3.60	630	15.60	2,730
Tunnel, shaft, and gate chamber	1,100	Cubic yard	14.00	15,400	3.60	3,960	17.60	19,360
Spillway	1,950	Cubic yard	11.00	21,450	3.60	7,020	14.60	28,470
Control house	20	Cubic yard	20.00	400	4.00	80	24.00	480
Spillway bridge	200	Cubic yard	15.00	3,000	4.00	800	19.00	3,800
METALWORK								
Metal:								
Trash rack	25,000	Pound	.02	500	.08	2,000	.10	2,500
Reinforcement steel	284,000	Pound	.02	5,680	.03	8,520	.05	14,200
Spiral stairway	17,500	Pound	.03	525	.11	1,925	.14	2,450
Water stops	400	Linear foot	.30	120	.40	160	.70	280
72-inch ring-follower gate and control mechanism	51,000	Pound	.04	2,040	.24	12,240	.28	14,280
60-inch needle valve and control mechanism	58,000	Pound	.03	1,740	.22	12,760	.25	14,500
12-ton hand hoist	35,000	Pound	.02	700	.19	6,650	.21	7,350
Gas-electric generator set and equipment	(1)	(1)	(1)	200	(1)	800	(1)	1,000
Miscellaneous metalwork	2,000	Pound	.10	200	.10	200	.20	400
Grout and drain pipe	5,300	Pound	.05	265	.07	371	.12	636
MISCELLANEOUS ITEMS								
Items:								
Control house except concrete	(1)	(1)		200		800	(1)	1,000
Transporting freight, except cement, for Government from Monte Vista, Colo., to the dam site (43.5 miles)	250	Ton	4.80	1,200				1,200
Highway construction	1	Mile		5,000				5,000
Clearing reservoir	100	Acre	25.00	2,500			25.00	2,500
Subtotal				399,197		77,802		476,999
Contingencies, 15 percent								71,550
Total estimated field cost								548,549
Investigations and surveys	(1)						(1)	5,000
Engineering and inspection, 6 percent								32,913
Superintendence and accounts, 1½ percent								8,228
General expense, 2½ percent								13,714
Total estimated cost								608,404
Cost per acre-foot storage								19.01

1 Lump sum.

chamber. A 6-foot by 14-foot lined shaft will extend from the valve chamber to the top of the dam, where it will be surmounted by a control house provided with a 12-ton hoist. A gas engine generator set will be provided for lighting and operating purposes. The trash rack atop the tunnel permits a silting depth for the reservoir. The outlet end of the tunnel discharges into the stilling basin.

Water supply. A run-off record for the Mogote station, 8 miles below no. 1 site, from 1912 to 1935, inclusive, is the only record on the Conejos River applicable to this study. Run-off at no. 6 site was estimated by the precipitation altitude method. Precipitation records at 10 stations in the San Luis Valley and adjoining watersheds, varying in elevation from 7,600 to 11,500 feet, are available but so widely scattered that their deviation from an average curve is quite great. The estimated run-off is as follows:

	Acre-feet		*Acre-feet*
1912	55, 900	1924	51, 100
1913	28, 100	1925	42, 000
1914	46, 000	1926	44, 700
1915	42, 800	1927	62, 000
1916	66, 000	1928	34, 400
1917	58, 700	1929	61, 100
1918	40, 500	1930	36, 800
1919	44, 400	1931	27, 100
1920	77, 300	1932	64, 200
1921	46, 700	1933	39, 100
1922	55, 300	1934	18, 700
1923	70, 900	1935	55, 500

Mean, 1912-35, inclusive, 48,700 acre-feet.

These estimates agree quite closely with results secured by modifying the altitude run-off curves used on the San Juan-Chama studies.

The reservoir capacity of 32,000 acre-feet represents the average amount storable, considering only the direct-flow uses on Conejos, and without regard for prior rights on Rio Grande, whether in Colorado, New Mexico, or Texas. In some years the amount so storable will fall to amounts not exceeding 20,000 acre-feet.

Mogote Reservoir

The dam is located approximately 5 miles northwest of Antonito, Colo., in section 4, T. 33 N., R. 8 E., N. M. P. M.

Summary of estimate data.

Storage capacity	30,000 acre-feet
Spillway capacity	Emergency only.
Outlet capacity	400 second-feet
Elevation, top of dam	8,045.
Maximum reservoir water-surface elevation, spillway level.	8,040.
Maximum height of dam	95 feet.
Estimated cost, dam and reservoir	$394,000.
Estimated cost of canal	$352,000.
Total cost, reservoir and canal	$746,000.
Topography of reservoir and geological sections.	Fig. 139.
General plan and sections	Fig. 140.
Preliminary estimate of dam	Table 16.
Preliminary estimate of canal	Table 17.

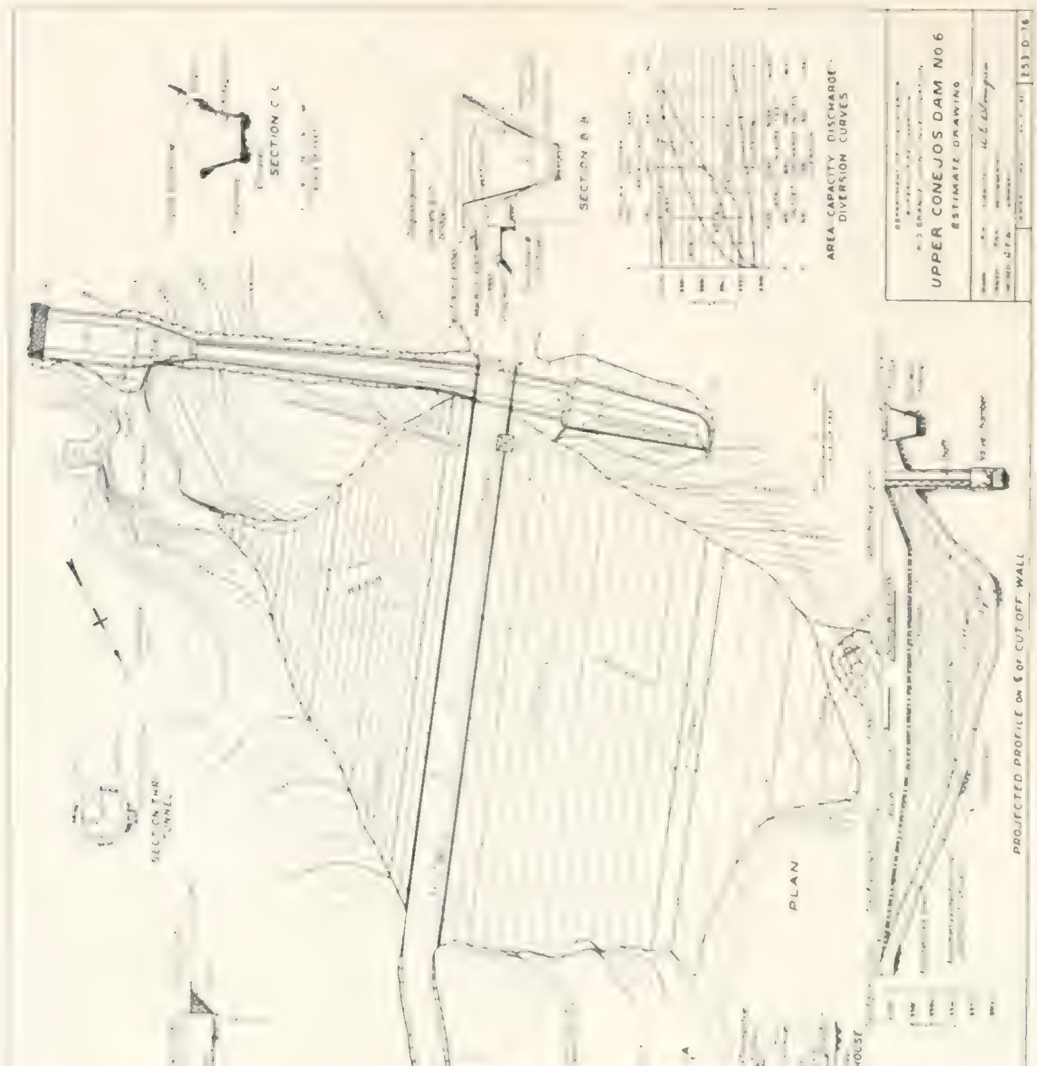
The reservoir area at elevation 8,040 is 970 acres. No clearing will be required. Flood waters of the Conejos River are to be diverted into this basin by means of a feeder canal and short tunnel.

Geology.—The oldest rocks exposed in the vicinity of the reservoir basin are the Potosi series, a great thickness of dense, crystalline, volcanic flows of Miocene Age. Overlying this series is a thickness of 400 feet or more of gravels, sands, and silts. Capping the gravel and silt member is a thin basalt lava flow. Locally, erosion has cut through the basalt cap and carved irregular basins in the gravel and silt member. The proposed reservoir area is in such a basin.

The most important features involved in the utility of the reservoir basin are: (1) The great depth to the water table and (2) the permeability of the silts and gravels beneath the reservoir floor. A drill hole at the dam site, elevation 7,957, penetrated 252 feet of silts, sands, and gravels without encountering the water table. Over the reservoir floor with a minimum thickness of about 50 feet at the dam site is a fine rather compact silt. Laboratory tests on an undisturbed sample of the material indicate percolation rates of .6 feet per year under a unit head.

Under the silt is a series of stratified and unstratified layers of gravel, boulders, volcanic ash, and tuff. Part of this series is stream laid, while the unstratified members are probably torrential wash. Nearly all of the members below the silt layer are very porous. Water pumped into a drill hole drained rapidly away. Overlying the silt member around the rim of the reservoir is a layer of about 20 feet of coarse gravel and boulders. A cut near the dam site showed it to be well cemented with lime at this locality. At other points it may be very porous. Overlying the coarse gravel is a thin flow of black basalt, probably about 25 feet thick. Like all thin surface flows, it is badly jointed and fractured. The whole series dips slightly (about 5°) to the east.

From the available data it has been concluded that some leakage must be expected at this site. There are material differences of opinion on the extent of such leakage. It is unlikely, however, that such leakage will be of an extent that will preclude filling in most years, as Conejos River flows not locally needed for irrigation far exceed the reservoir capacity, except in rare years like 1931 or 1934. No opinion is here presented as to the extent of waters storable, considering all rights to the water of Rio Grande and its tributaries in Colorado, New Mexico, and Texas.



SECTION C-C
SECTION B-B
AREA-CAPACITY DISCHARGE-DIVERSION CURVES
UPPER CONEJOS DAM No 6
ESTIMATE DRAWING
253-D-16
PLAN
PROJECTED PROFILE ON ℄ OF CUT OFF WALL
SECTION THRU TRASHRACK-VALVE CHAMBER-SHAFT CONTROL HOUSE
TYPICAL EMBANKMENT SECTION
SECTION A-A
SECTION D-D
EXPLANATION
SECTION ON ℄ OF SPILLWAY
SECTION THR TUNNEL

FIGURE 138

The stratigraphy at the dam site is the same as that of the reservoir basin. The foundation and abutments consist of the yellow compact silt which covers the floor of the reservoir basin. The 20-foot layer of coarse gravel and boulder overlies the silt member and is overlain by the basalt lava flow. Rapid erosion of the softer silt and gravel has undermined the basalt cap, causing blocks and fragments of the lava formation to break away and mantle the abutments with talus. A test pit on the left abutment showed about 10 feet of angular blocks covering the silt member.

Dam.—A compacted earth- and rock-fill type of dam was selected for this site because of the close proximity of sufficient suitable embankment materials and the unsuitability of foundation for any other type. Bedrock is too far below the surface to be considered for the dam foundation. Sand and gravel for concrete aggregate is probably available within 2 miles of the

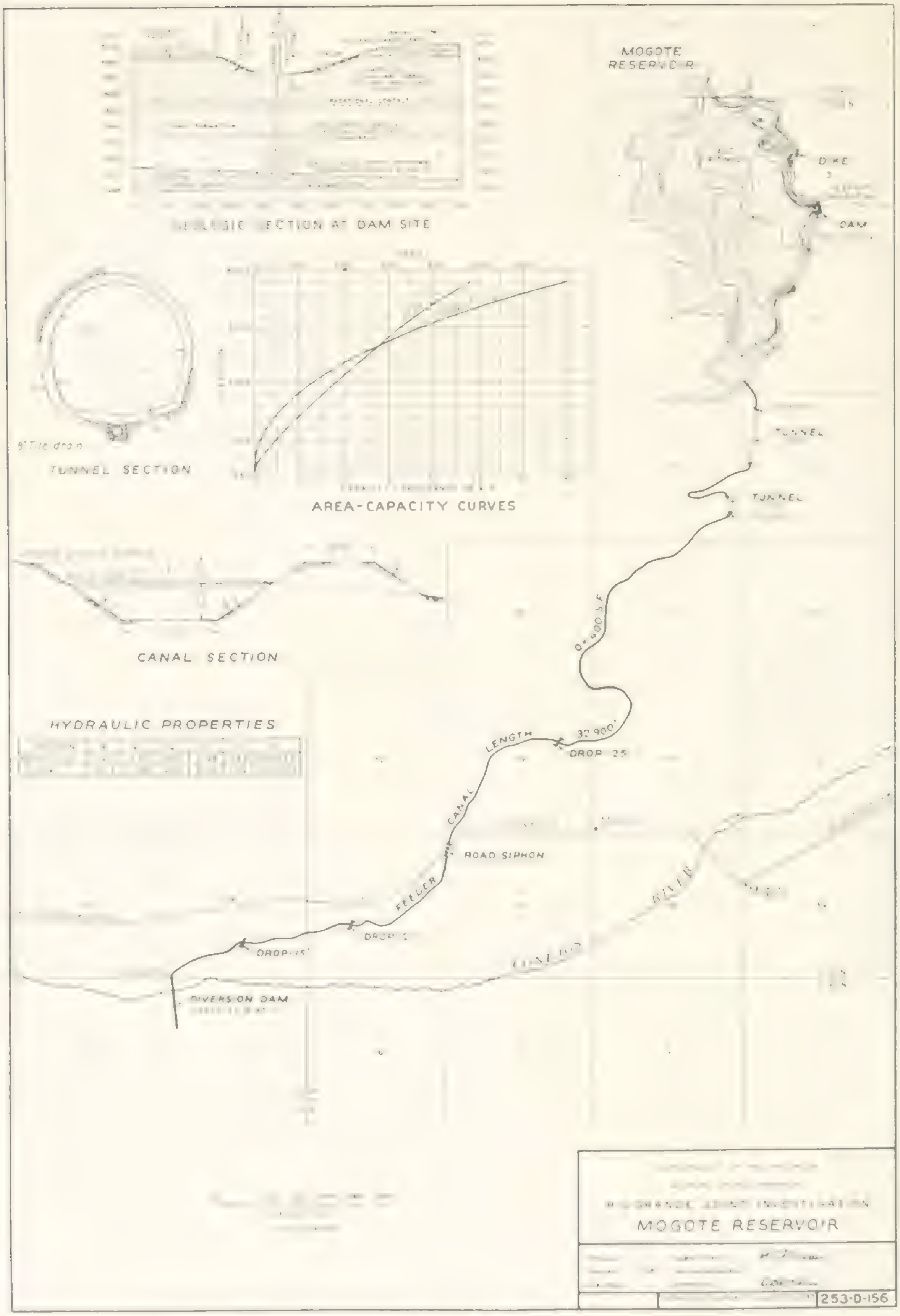
TABLE 16.—*Mogote Dam, preliminary estimate, August 1937*

[Earth embankment; top of dam, elevation [illegible]; normal water surface, elevation 8,040; maximum water surface, elevation [illegible]; [illegible]]

[Storage capacity, 30,000 acre-feet; spillway capacity, emergency only; diversion capacity, none; required outlet capacity, 400 second-feet]

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
EARTHWORK								
Excavation, common:								
Stripping dam foundation	16,700	Cubic yard	$0.30	$5,010			$0.30	$5,010
Stripping borrow pits	13,000	Cubic yard	.30	3,900			.30	3,900
Toe drains and cut-off trenches	10,200	Cubic yard	.40	4,080			.40	4,080
Outlet works, open cut	4,300	Cubic yard	.40	1,720			.40	1,720
Outlet works, tunnel and gate chamber	2,050	Cubic yard	10.00	20,500			10.00	20,500
Borrow and transportation to dam	337,000	Cubic yard	.25	84,250			.25	84,250
Excavation, rock:								
Cut-off walls	350	Cubic yard	4.00	1,400			4.00	1,400
Borrow and transportation to dam	36,000	Cubic yard	.75	27,000			.75	27,000
Emergency spillway	1,700	Cubic yard	1.00	1,700			1.00	1,700
Embankment:								
Earth-fill compacted	300,000	Cubic yard	.10	30,000			.10	30,000
Dumped rock on downstream slope	35,500	Cubic yard	.20	7,100			.20	7,100
Riprap rock on upstream slope	15,600	Cubic yard	.40	6,240			.40	6,240
Riprap rock in outlet channel	125	Cubic yard	1.00	125			1.00	125
Gravel for roadway	1,120	Cubic yard	1.25	1,400			1.25	1,400
Backfill about structures	300	Cubic yard	.50	150			.50	150
DRAINAGE								
Drain tile:								
12-inch diameter clay tile in gravel	750	Linear foot	.70	525	$0.50	$375	1.20	900
8-inch diameter clay tile in gravel	750	Linear foot	.60	450	.30	225	.90	675
CONCRETE WORK								
Concrete:								
Cut-off walls	150	Cubic yard	12.00	1,800	3.75	563	15.75	2,363
Parapet and curb walls	250	Cubic yard	17.10	4,275	4.15	1,038	21.25	5,313
Trash rack and transition	100	Cubic yard	14.35	1,435	4.15	415	18.50	1,850
Gate chamber below floor	50	Cubic yard	9.00	450	3.75	188	12.75	638
Gate chamber above floor	50	Cubic yard	18.00	900	4.50	225	22.50	1,125
Tunnel lining	740	Cubic yard	15.25	11,285	4.50	3,330	19.75	14,615
Stilling basin	120	Cubic yard	13.75	1,650	4.15	498	17.90	2,148
Control house substructure and portal	125	Cubic yard	16.25	2,031	4.15	519	20.40	2,550
Control house superstructure	25	Cubic yard	21.35	534	4.50	112	25.85	646
Special finishing concrete surfaces	425	Square yard	.60	255			.60	255
METALWORK								
Metal:								
Trash rack	18,500	Pound	.02	370	.08	1,480	.10	1,850
Reinforcement bars	100,000	Pound	.02	2,000	.035	3,500	.055	5,500
Pipe handrailing	1,100	Pound	.10	110	.10	110	.20	220
1 48-inch needle valve and control mechanism	37,600	Pound	.03	1,128	.22	8,272	.25	9,400
1 57-inch ring-follower gate, lining, and control mechanism	43,600	Pound	.04	1,744	.24	10,464	.28	12,208
1 8-ton hoist	28,000	Pound	.02	560	.19	5,320	.21	5,880
Gas electric generator set and equipment	[illegible]		(1)	200	(1)	800	(1)	1,000
100 feet of 57-inch I. D. steel pipe	107,000	Pound	.05	5,350	.10	10,700	.15	16,050
Miscellaneous	6,000	Pound	.10	600	.10	600	.20	1,200
Furnishing and placing liner plate	185,000	Pound	.08	14,800			.08	14,800
MISCELLANEOUS ITEMS								
Items:								
Control house except concrete			(1)	800		700	(1)	1,500
Transporting freight except cement for Government from Antonito, Colo., to dam site (25 miles)	200	Ton	1.00	200			1.00	200
Right-of-way	970	Acre			10.00	9,700	10.00	9,700
Subtotal				248,027		59,134		307,161
Contingencies, 15 percent								46,074
Total estimated field cost								353,235
Investigations and surveys								[illegible]
Engineering and inspection, 6 percent								21,194
Superintendence and accounts, 1½ percent								5,298
General expense, 2½ percent								[illegible]
Total estimated cost								[illegible]
Cost per acre-foot of storage								13.12

1 Lump sum.


MOGOTE
RESERVOIR
DIKE
DAM
TUNNEL
TUNNEL
TUNNEL SECTION
AREA-CAPACITY CURVES
CANAL SECTION
HYDRAULIC PROPERTIES
DROP 25
ROAD SIPHON
FEEDER CANAL LENGTH 32,900'
DROP 15'
DIVERSION DAM
RIVER
MOGOTE RESERVOIR
253-D-156

site, although no pits have been dug. Embankment materials can be obtained in the reservoir area, just above the dam site.

The proposed rolled-earth and rock-fill dam has a crest length of 645 feet and attains a maximum height of 95 feet above the stream bed.

The embankment has a crest width of 35 feet at elevation 8,045 and carries a graveled roadway with typical concrete parapets and curbs. The upstream face, protected with a 3-foot layer of dumped rock riprap has a 3:1 slope. The downstream face is formed by a rock-fill of increasing thickness from crest to toe, that has an outer slope of 2½:1 to elevation 7,992, a 6:1 slope down to elevation 7,970, and 1½:1 slope terminating at the foundation level. Beneath the rock-fill, which has a minimum thickness of 5 feet at the crest, is the rolled semi-impervious section which has a slope of 2¼:1. An inverted filter will be incorporated in base of the rock-fill. A cut-off trench 15 feet deep is placed under the impervious section of the dam. Stripping of vegetation for the entire area of the dam is provided.

A dike approximately 300 feet long and 25 feet in maximum height will be required in the saddle about 1,800 feet to the northwest of the dam. This dike is similar to the dam in section, except that rock-fill at downstream toe is decreased. An emergency spillway consisting of an open cut channel in the basalt cap rock 1,800 feet northwest of the left abutment of the dam was provided in the plan. This channel will be 25 feet in bottom width with ¼:1 side slopes. The bottom of the channel will be at elevation 8,035 with a fuse plug built to maximum water surface. The channel is near the right abutment of the dike and spills downstream from the dike into the saddle. The outlet works consist of a concrete-lined tunnel under the left abutment of the dam. The tunnel has an internal diameter of 5 feet upstream from the gate chamber and the downstream section is 9 feet in diameter. The gate chamber, containing one 57-inch ring follower emergency gate, is placed under the axis of the dam. A 57-inch steel pipe conduit through the 9-foot diameter tunnel connects the emergency gate chamber with the 48-inch needle valve in the valve house at the downstream portal of the tunnel. A stilling basin is provided to prevent erosion from the needle valve discharge.

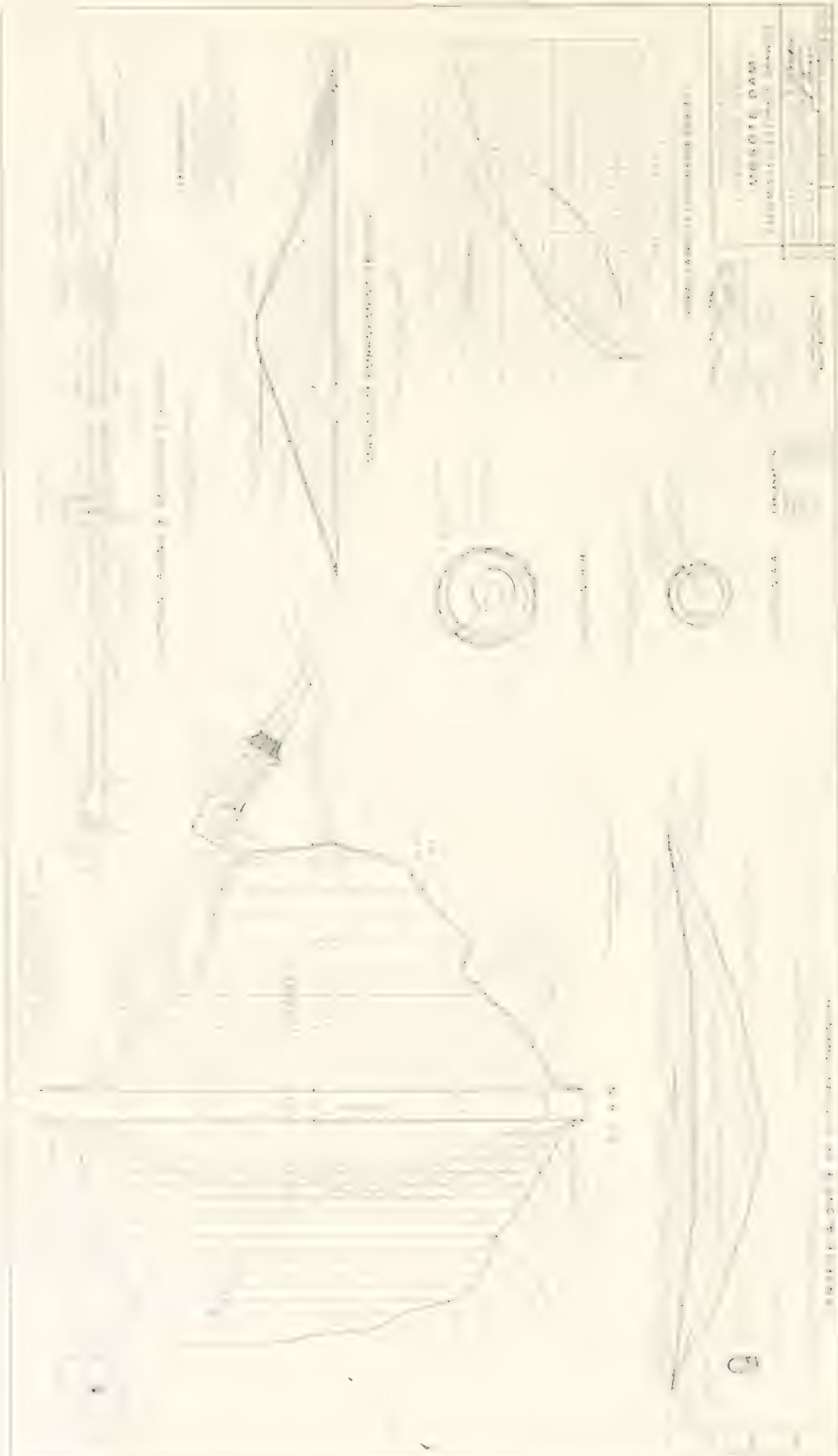
Provisions are made in the estimate for steel liner plate for the tunnel. The outlet works will provide a discharge capacity of 400 second-feet with the reservoir half full or a water surface at elevation 8,018.

Mogote Creek is a small intermittent stream that discharges into Conejos River. Owing to the small

TABLE 17.—*Mogote Canal estimate*

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
Diversion:								
Diversion and care of river	(1)			$5,000				$5,000
Excavation, common	16,000	Cubic yard	$0.50	8,000			$0.50	8,000
Excavation, structure	1,100	Cubic yard	1.00	1,100			1.00	1,100
Embankment	600	Cubic yard	.75	450			.75	450
Backfill	300	Cubic yard	.25	75			.25	75
Riprap	1,200	Cubic yard	1.50	1,800			1.50	1,800
Concrete	2,000	Cubic yard	18.00	36,000	$3.75	$7,500	21.75	43,500
Reinforcement steel	265,000	Pound	.02	5,300	.035	9,275	.055	14,575
Slide gates and hoists	10,000	Pound	.05	500	.25	2,500	.30	3,000
Radial gate and hoist	1,500	Pound	.05	75	.15	225	.20	300
Canal:								
Excavation, common	147,000	Cubic yard	.15	22,050			.15	22,050
Excavation, rock	15,000	Cubic yard	.75	11,250			.75	11,250
Excavation, structure	315	Cubic yard	.75	236			.75	236
Backfill	700	Cubic yard	.25	175			.25	175
Riprap	3,800	Cubic yard	1.50	5,700			1.50	5,700
Concrete, structure	370	Cubic yard	18.00	6,660	3.75	1,388	21.75	8,048
Reinforcement steel	47,600	Pound	.02	952	.035	1,666	.055	2,618
Turnouts		10	200.00	2,000	50.00	500	250.00	2,500
Farm bridges		15	200.00	3,000			200.00	3,000
Tunnels, 7-foot diameter; L=560 and 1,950 feet:								
Excavation, all classes	5,375	Cubic yard	15.00	80,625			15.00	80,625
Concrete lining	1,355	Cubic yard	18.00	24,390	5.00	6,775	25.00	31,165
Steel rib supports	87,100	Pound	.08	6,968			.08	6,968
Timber	75.3	M ft. b. m.	80.00	6,024			80.00	6,024
Drains	2,510	Linear foot	1.00	2,510	.50	1,255	1.50	3,765
Right-of-way	100	Acre foot			50.00	5,000	50.00	5,000
Property damages	(1)					5,000		5,000
Fencing right-of-way	12.5	Mile	350.00	4,375			350.00	4,375
Subtotal				235,215		41,084		276,299
Contingencies, 15 percent								41,445
Total estimated field cost								317,744
Investigations and surveys								3,000
Engineering and inspection, 6 percent								19,065
Superintendence and accounts, 1½ percent								4,766
General expense, 2½ percent								7,941
Total estimated cost								352,519

[1] Lump sum.


COYOTE DAM

flows in the creek no special provisions are necessary for diversion during construction as the outlet tunnel will easily handle any anticipated stream flow.

This dam can probably be constructed in one season. There are no improvements within the reservoir area. No clearing will be necessary. The reservoir area is mainly used for grazing and the cost of right-of-way should not exceed $10 per acre. No construction camp or permanent building will be required owing to the short distance by dirt road to Antonito, where it is assumed that suitable housing facilities for construction workmen and the dam caretaker can be obtained.

Feeder Canal.—A canal of 400 second-foot capacity was surveyed, diverting from the Conejos River in section 1, T. 32 N., R. 7 E., N. M. P. M., to fill Mogote Reservoir. The canal is 39,500 feet long with two tunnels 560 feet and 1,950 feet long. Strip topography of the entire route was secured and an estimate prepared as shown in table 14B.

The diversion dam in Conejos River is one of the major items of cost, and is 2 miles upstream from the elevation required, in order to secure a gravity diversion from a stabilized section of the river channel. Three drops then became necessary to absorb the excess fall from the diversion dam. No feasible route could be found to avoid the two tunnel locations.

Wagon Wheel Gap Reservoir

Summary of data:

Storage capacity	1,000,000 acre-feet.
Spillway capacity	10,000 second feet
Regulated outlet capacity	5,000 second feet
Elevation, top of dam	8,780
Elevation of parapets	8,783
Normal reservoir water-surface elevation.	8,773.
Maximum reservoir water-surface elevation.	8,780.
River level	8,440.
Maximum height of dam to bedrock	430 feet.
Total estimated cost of dam	[1] $11,301,861.
Preliminary estimate	Table 17.
Reservoir topography	Fig. 141.
General plan and sections	Fig. 142.

In accordance with agreements covering the program of the investigations, the plan and estimate is for a reservoir of 1,000,000 acre-feet, and no water supply studies have been made.

General Data

Wagon Wheel Gap dam site is located on the Rio Grande about 9 miles southeast of Creede, Colo., in Mineral County. It is 32 miles from Del Norte, Colo. The Creede branch of the Denver & Rio Grande Western Railroad runs directly through the dam site and nearly the full length of the reservoir. The reservoir was surveyed and mapped by Shrive B. Collins in April 1909. The topography and area map is no. 5802, filed by Chas. W. Comstock, May 6, 1909, at the office of the State engineer of Colorado. An assumed datum was used for that map and survey with zero elevation apparently at river level. A flow line survey traversed the 300-foot level. The initial point of this survey and three of the points on the axis of the dam were tied into the 1936 surveys. The zero elevation of the original survey corresponds within .5 foot of United States Geological Survey elevation 8,440.

Planetable topography of dam and spillway site on a scale of 1 inch=50 feet, with contour interval of 5 feet, was secured by the Bureau of Reclamation in 1936.

Reservoir Geology

Basement rocks of the region are pre-Cambrian granites and gneisses, above which in the order of their deposition are the following formations, all of which are exposed somewhere in the immediate region.

1. Conejos andesite.
2. Treasure Mountain quartz latite.
3. Sheep Mountain andesite.
4. Alboroto quartz latite.
5. Huerto andesite.
6. Piedra rhyolite.
7. Creede sedimentaries.
8. Fisher latite.

Erosion periods of varying length and intensity followed each eruption, so that each succeeding flow filled the eroded valleys and canyons. The Creede sedimentaries and Fisher latites, being the latest deposits, are now the predominate formations in the reservoir area and at the dam site. The present topography is the result of an extremely long erosional period following the Piedra eruptions during which uplift in Pleistocene and recent times rejuvenated the streams to etch the present-day relief. The history of this section of the Rio Grande during Tertiary times is complex. Flows time and again must have dammed or changed its course. After the uplift, the river for some undetermined reason did not entrench itself in the neighboring Creede sedimentaries, but became caught in the Fisher Latite to form the present canyon, a canyon that is not at all the result of faulting or other structural disturbances. Glaciers reached no farther than about 3 miles upstream from the flow line of the reservoir, but outwash from that period is observable as terrace remnants in the reservoir basin and as recent gravels in the foundation.

No indication of unsatisfactory reservoir conditions have been found. Normal seep and spring occurrences indicate a water table tributary to the river. The basin is heavily mantled with terrace and recent river gravels to a depth of at least 50 to 100 feet. Side wash, fan,

[1] [illegible]

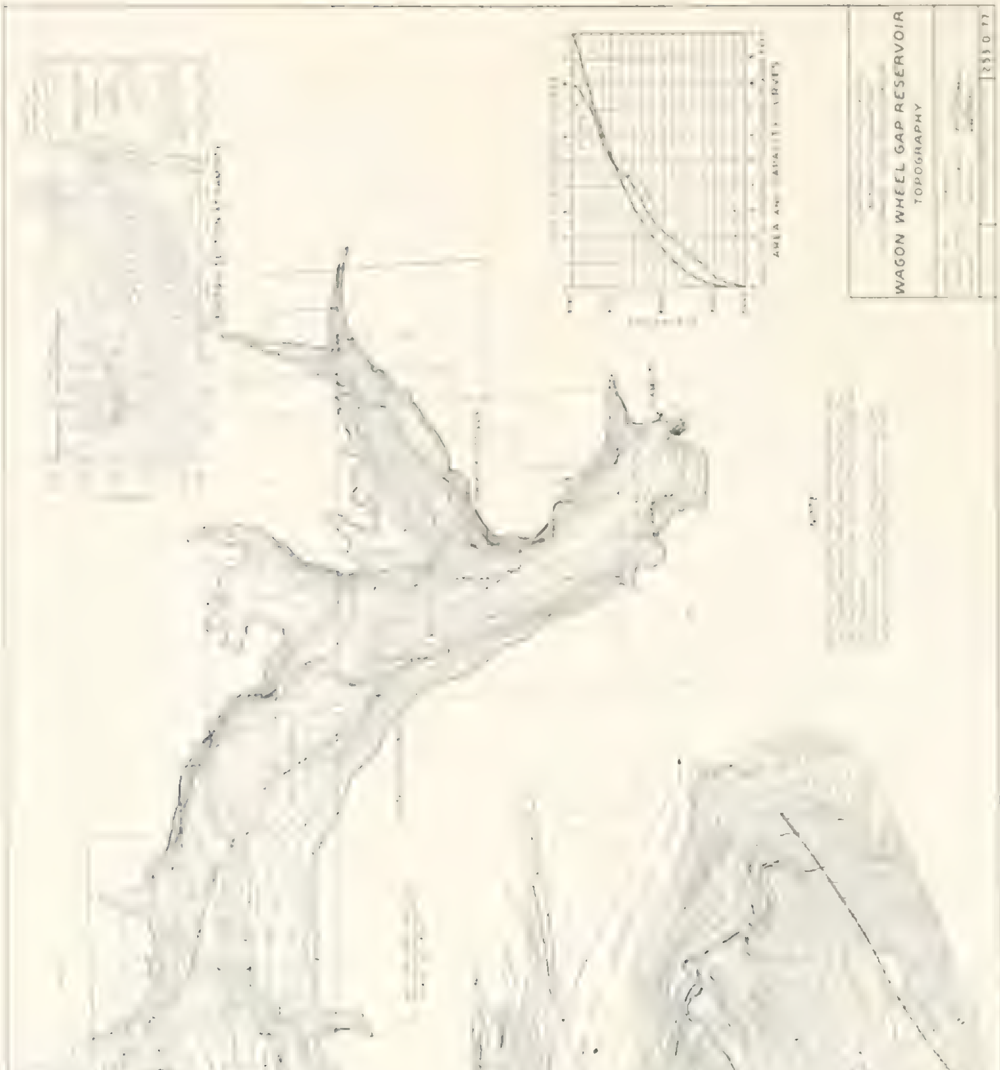


PLATE 111

slough, and other detrital deposits are now progressively covering the bottom gravels.

The immediate bedrock is Creede sedimentary tuffs, shales, and sandstones. In turn, this rests on an older valley floor of volcanic flows. In the vicinity of the dam site a massive latite (Fisher) flow rests on the Creede shales to form a bottle neck, across which the river flows and which forms the barrier responsible for the formation of the flat basin itself.

Considering the volcanic rock character and the compact Creede sedimentaries filling the older Rio Grande Channel as well as mantling the basin, little, if any, reservoir seepage can occur.

Dam Site Geology [4]

The rock forming the foundation and abutments is the Fisher andesite or latite, a dark, fine-grained flow rock with numerous larger crystals or phenocrysts of feldspar, biotite, and hornblende. It is massive, hard, and competent. Some jointing and minor fracturing is noted but water tests in the drill holes showed that these planes are tight at depth. Flow lines are evident and occasionally a soft, thin, interbedded ash layer is found. The latter inclusions become more prevalent at depth or toward the spillway saddle.

The walls of the canyon are unusually sheer, but some local areas at the base are mantled with talus detritus composed of angular rock and fragments with little interstitial silt, which, together with the bottom gravels must be entirely excavated. Some local pockets on the right abutment near the spillway contain a veneer (3–5 feet) of wash material.

Beneath the present river bed, the V-shaped canyon formerly cut in the bedrock is filled to a maximum depth of 80 feet with a roughly stratified mixture of boulders, cobbles, gravel, and sand in a loose, porous deposit. Boulders became more prominent with depth. Beneath the gravel, the rock is somewhat shattered and broken for depths of 5 to 10 feet but then becomes hard, dense, watertight and competent.

A drill hole 305 feet deep (246 feet in rock) failed to penetrate through the latite. Creede sedimentaries probably underlie, but there is a remote possibility that at this particular location the Creede may be entirely eroded and the latite resting directly on one of the other basement flows.

In either event the thickness of rock beneath the foundation should be sufficient to withstand any pressures imposed upon it by the dam. The Creede formation itself, wherever observed, appears compact and adequately impervious.

Neither abutment offers problems of consequence.

All of the Fisher andesite flows show some development of joints and an obvious flow structure. The joints appear to be tight and when free from weathering influences should offer no difficulty. These joints do not extend laterally over great distances, but appear to be a poorly developed columnar type, running at all directions, but always perpendicular to the cooling surfaces.

On the other hand, the horizontal flow lines extend uniformly over large distances. These are planes parallel to the cooling surfaces (top and bottom) which, rather than cleavages, are marked changes in the textural quality of the andesite. They are believed to originate, during the extrusion and subsequent cooling, by temperature differences. Often they mark boundaries between thin ashy inclusions. Such planes are almost invariably tight and no seepage can be expected from this source. All observed fractures were clean and are believed to be susceptible to grouting, if and when any seepage is found.

The andesite, on the whole, dips slightly upstream and more steeply into the canyon. To the northeast the dip varies widely, becoming steeper toward the right where it is measured at 60°. At the top of the right abutment the strike is N. 30° W., dip 30° NE., while on the top of the left abutment it has flattened to strike N. 30° W., dip 5°–10° NE.

A fault parallels the river through the saddle on the right abutment, the downthrown block on the river side, bringing the andesite into juxtaposition to the normally underlying Creede sedimentaries.

It is believed that this faulting has induced much of the folding that is noted in the andesite flows at the dam site. That the dip steepens progressively against the fault is suggestive, while unquestioned drag folding of the Creede sedimentaries has been noted on the other side. However, some of the folding may be of original flow origin. There is no evidence of recent movement.

There is little doubt as to the tight character of the andesite at the dam and little suspicion of the saddle sedimentaries is held in view of their compact character and the excessive distance the water must travel.

Dam

The dam site is very well adapted to a concrete arch type of dam. Studies and estimates were made for a concrete gravity dam as well as for other sections of arch dams. There is an ample supply of sand and gravel deposits of good quality both upstream or downstream from the dam site.

Figure 142 shows the general plan and sections of the proposed dam and spillway. The main dam will be 1,200 feet long at the crest and attains a maximum height of 430 feet above the foundation. The arch section as shown on the drawing has a 20-foot crest at elevation 8,780, with typical concrete curbs and 3-foot

[4] See geologic section, fig. 141.

parapets. The upstream and downstream face of the dam is curved in section as well as in plan. The dam is designed as a constant angle arch type as closely as the topography will permit.

One line of grout holes at 5-foot centers 50–125 feet deep and several lines of grout holes at 10-foot centers, staggered, 40 feet deep, are contemplated. One line of drain holes at 10-foot centers, 75 feet deep, connect with a drainage and grouting gallery.

Spillway

A straight uncontrolled overflow type of spillway will be located in a saddle approximately 560 feet from the right abutment. This spillway crest at elevation 8,773 is 140 feet long. With the water at its maximum elevation of 8,780 or 7 feet over the crest, the discharge will be 10,000 second-feet. The spillway will be constructed entirely on sound rock and concrete lining does not appear to be necessary below the apron, as the outlet capacity provided will enable full control of practically all floods without the use of the spillway. A channel with a 50-foot bottom width will be excavated in rock for a short distance below the apron and discharge into a natural channel leading to the river approximately 1,500 feet downstream from the dam.

Outlet Works

The outlet works consists of two 10.5 foot diameter steel lined conduits placed at elevation 8,475 branching into four 79-inch diameter conduits at the downstream side of the dam. Four 79-inch diameter paradox gates and four 66-inch needle valves will be located at the downstream slope of the dam in a needle-valve house. The gates and valves will be installed as shown on the drawing. It is planned to install a gas engine electric generator set for lighting and operation purposes.

With the water-surface elevation 8,542 in the reservoir (the 50,000 acre-foot level) the outlet works will discharge the required 5,000 second-feet.

Miscellaneous Cost Items

During May 1937, survey parties relocated the highway, took strip topography throughout and prepared an estimate of cost. A major item is the construction of a high bridge across the river near the upper end of the reservoir. State highway officials have given welcome advice on the relocation. Including a branch road from the upper end of the reservoir to Creede, a total of 21 miles of road will be rebuilt. The road was estimated with a 23-foot base, 6-inch gravel surfacing, maximum 6 percent grade and 20° curves. The route selected starts about one-fourth of a mile below the dam site, climbs to the saddle on the right abutment with a uniform gradient, then follows the right bank of the reservoir to the upper end approximately on a water grade. From Creede the new route leaves the town at the present location of the Lake City road but climbs to a 9,000-foot elevation within a short distance and maintains that elevation until it joins the route on the south side of the reservoir.

An alternative route along the north or left side of the reservoir was considered but discarded because of the excessive curvature, steeper grades and higher elevations required. For several miles the route would be at elevations of over 10,000 feet which would be exceptionally difficult to keep open in the winter months. The route would be a few miles shorter from Creede to a point below the dam but longer in time required for travel from Creede.

There are 8,500 acres of land to be submerged in the reservoir; its ownership and estimated value is as follows:

	Acres	Estimated value
Private land	[illegible]	[illegible]
State-owned land	[illegible]	[illegible]
U. S. [illegible] Bureau	[illegible]	
U. S. National Forest	[illegible]	
Total	[illegible]	383,410

[1] $50 per acre.
[2] [illegible] per acre.

Property damage, which covers several farm buildings, about 100 tourist cabins and miscellaneous structures, is estimated at $150,000; telephone lines, 20 miles at $1,500, $30,000; removal of Federal fish hatchery, $50,000.

Information furnished by State officials is to the effect that the Denver & Rio Grande Western Railroad Co. has agreed if the reservoir is built, to petition the Public Utilities Commission of Colorado and the Interstate Commerce Commission for the abandonment of that part of the railroad from Wagon Wheel Gap to Creede, which is the present end of the line. If such is done and the petition is granted, there will be no additional cost to the reservoir. The cost of reconstruction has not been determined but it would probably be fully $2,000,000. An item of $25,000 for salvaging the present roadbed has been included in this estimate. There is also included an item of $75,000 for the construction of a secondary road from Creede along the left side of the reservoir to give access to points now reached from the bottom of the basin.

Diversion During Construction

It is estimated that river diversion and unwatering of foundations will cost about $100,000. River diversion during construction can be handled in two ways—a 12-foot diameter unlined horseshoe tunnel 1,000 feet long can be driven through the rock under the right abutment of the dam; or inlet and outlet flumes

TABLE 17.—*Wagon Wheel Gap Dam preliminary estimate, Aug. 1, 1937*

[Concrete arch: Top of dam, elevation 8,780; spillway crest, elevation 8,773; normal water surface, elevation, 8,773; maximum height of dam, 430 feet; drawing no. 253-D-78]

[Storage capacity, 1,000,000 acre-feet; spillway capacity, 10,000 second-feet; required outlet capacity, 5,000 second-feet; at elevation 8,542 (50,000 acre-feet)]

[illegible]	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	[illegible]	[illegible]	[illegible]	Total cost	Unit cost	Total cost	[illegible]	Total cost
RIVER WORK								
[illegible]	(1)		[illegible]	$100,000			[illegible]	$100,000
EARTHWORK								
[illegible]								
[illegible]	[illegible]	[illegible]	[illegible]	185,000			[illegible]	185,000
[illegible]	[illegible]	[illegible]	1.25	11,250			[illegible]	11,250
Excavation, rock:								
[illegible]	221,000	Cubic yard	3.00	663,000			3.00	663,000
[illegible]	6,000	Cubic yard	3.50	21,000			3.50	21,000
Embankment: Backfill about structures	4,000	Cubic yard	.75	3,000			.75	3,000
[illegible]								
Drilling:								
[illegible]	500	Linear foot	1.00	500			1.00	[illegible]
[illegible]	6,000	[illegible]	2.00	12,000			2.00	12,000
Grout holes 50 to 100 feet deep	11,200	Linear foot	2.50	28,000			2.50	28,000
[illegible]	18,800	[illegible]	3.00	56,400			3.00	56,400
[illegible]	12,200	Linear foot	2.50	30,500			2.50	30,500
Pressure grouting:								
[illegible]	45,000	Cubic foot	1.00	45,000	$1.00	[illegible]	2.00	90,000
[illegible]	5,300	Cubic foot	2.00	10,600	[illegible]	7,155	3.35	17,755
[illegible]	24,000	Linear foot	.60	14,400	.07	1,680	.67	[illegible]
[illegible]								
Concrete:								
[illegible]	885,500	Cubic yard	3.25	2,877,875	3.25	2,877,875	6.50	5,755,750
[illegible]	400	Cubic yard	18.00	7,200	4.00	1,600	22.00	8,800
Spillway	1,600	Cubic yard	4.00	6,400	3.25	5,200	7.25	11,600
[illegible]	3,150	Cubic yard	12.00	37,800	4.00	12,600	16.00	50,400
[illegible]	700	Cubic yard	20.00	14,000	4.00	2,800	24.00	16,800
[illegible]	6,500	Cubic yard	5.75	37,375	3.75	24,375	9.50	[illegible]
[illegible]	160	Cubic yard	7.25	1,160	3.75	600	11.00	1,760
[illegible]	400	Cubic yard	5.75	2,300	3.75	1,500	9.50	3,800
[illegible]	[illegible]		(1)	100,000			[illegible]	100,000
[illegible]	2,500	Square yard	.60	[illegible]			.60	1,500
[illegible]								
[illegible]								
Trash rack	125,000	Pound	.015	1,875	.06	7,500	.075	9,375
[illegible]	500,000	[illegible]	.02	10,000	[illegible]	15,000	.05	25,000
[illegible]	16,500	Linear foot	.25	4,125	.40	6,600	.65	10,725
Bulkhead gates, frames, and guides	35,000	Pound	.015	525	.09	3,150	.105	3,675
[illegible]	[illegible]	[illegible]	.025	9,250	.075	27,750	.10	37,000
[illegible]	[illegible]	Pound	.025	6,600	.245	64,680	.27	71,280
[illegible]	[illegible]	[illegible]	.025	8,100	.21	68,040	.235	76,140
[illegible]	[illegible]	Pound	.10	200	.10	[illegible]	.20	400
[illegible]	41,000	[illegible]	.10	4,100	.10	4,100	.20	8,200
[illegible]	79,000	[illegible]	.05	3,950	.07	5,530	.12	[illegible]
Pipe and fittings for contraction joint grouting	140,000	Pound	.10	14,000	.10	14,000	.20	28,000
[illegible]	[illegible]		[illegible]	[illegible]			[illegible]	3,000
[illegible]								
Items:								
[illegible]	(1)		[illegible]	3,000			[illegible]	3,000
[illegible]	300	Acre	25.00	7,500			25.00	[illegible]
[illegible]	[illegible]		[illegible]	400	[illegible]	1,600	[illegible]	2,000
Construction camp	[illegible]		[illegible]		[illegible]	60,000	[illegible]	60,000
[illegible]	[illegible]		[illegible]	692,272	[illegible]	68,741	[illegible]	761,013
[illegible]	7,547	[illegible]			50.00	377,350	50.00	377,350
[illegible]	203	Acre			30.00	6,090	30.00	6,090
[illegible]	[illegible]				[illegible]	200,000	[illegible]	200,000
[illegible]	20	Mile			1,500.00	30,000	1,500.00	30,000
[illegible]	(1)				[illegible]	50,000	[illegible]	50,000
[illegible]	15	[illegible]	4,000.00	60,000	1,000.00	15,000	5,000.00	75,000
[illegible]	[illegible]				(1)	25,000		25,000
Subtotal				5,095,157		4,030,716		9,125,873
[illegible]								1,368,881
[illegible]								10,494,754
[illegible]								20,000
[illegible]								524,738
[illegible]								104,948
[illegible]								157,421
[illegible]								11,301,861
[illegible]								11.30

[1] [illegible]

connecting with a conduit placed in the base of the dam can be used for the diversion of stream flow. Either installation will cost approximately the same, i. e., \$50,000. The sum of \$25,000 is included for plugging the tunnel or conduit system, and pumping and unwatering of foundations was estimated at \$25,000. It will be necessary to coordinate river diversion with the construction schedule.

Construction Schedule

It will require approximately 3 years to complete this dam. The first year would see construction of the river diversion system and the major portion of the dam excavation. Construction of the main dam can be started early in the beginning of the second year. The spillway excavation and concrete structure can also be completed in that year. In the third year, concrete pouring, finishing work on the structures, and installation of the outlet gates and valves can be completed.

Power Development

Provisions will be made for a future power installation by placing two 19-foot diameter tunnels (closed with plugs) through the dam for a later installation of two 13-foot diameter penstocks, and guides for future tractor gates and trash racks will be constructed on the face of the dam. No power items, other than those necessary for present construction, were included in this estimate.

The period 1911 to 1933, inclusive, was used in making the study of possible power production at Wagon Wheel Gap Reservoir.

The operation schedule for the reservoir was obtained from a study made by R. J. Tipton, consulting engineer for San Luis Valley interests. Mr. Tipton's schedule was for all the reservoirs on the Rio Grande above Wagon Wheel Gap. For this study his results have been modified to the extent that the capacity of Wagon Wheel Gap Reservoir alone has been used, assuming that the 150,000 acre-feet of storage capacity upstream would be ideally operated to regulate inflow to Wagon Wheel Gap Reservoir.

The power installation proposed consists of two 25,000-kilowatt generators with penstocks of 3,000-second-foot capacity at rated head of 250 feet. All irrigation releases and spills were assumed to be available for power generation up to the penstock capacity. As the lowest head to be encountered during the period covered by the study was in excess of 250 feet, a constant over-all efficiency was assumed for the power installation of 80 percent. At lower heads this efficiency could not be realized, but no modification was necessary for this study.

No correction for evaporation was made in this study, as allowance for evaporation from Wagon Wheel Gap Reservoir was made by Mr. Tipton in the gross demand upon the reservoir.

The reservoir releases and spills given in Mr. Tipton's tabulations have been used directly, except that the November-March period used in Mr. Tipton's study was broken down into months in this study whenever there were releases from the reservoir. The apparent discrepancies in power produced by the releases usable for power in the summary table are due to this breakdown into monthly values.

Table 18 is a summary of the detailed study of possible power production at Wagon Wheel Gap Reservoir. The study was carried through September of 1933, as that was as far as Mr. Tipton's study was based upon recorded discharge.

Power produced must be considered as secondary power only since the plant, as a rule, can only be operated during the irrigation season.

At an estimated cost of \$54 per kilowatt of installed capacity, the total cost of power installation at the dam will be \$2,700,000.

Power Market

A study of the trend of population growth in the San Luis Valley indicates a population of about 50,000 in 1950. At present, per-capita consumption of power probably does not exceed 500 kilowatt-hours annually. Very few of the farms are electrified. Development of power at Wagon Wheel Gap may make feasible the operation of numerous pumping plants in the valley designed to recover a part of the great amount of water now stored beneath the valley floor. For such a load the plant at Wagon Wheel Gap is ideally fitted. It may also have some value for use as a peak-load plant when operated in conjunction with existing power plants. A market for the entire output of the plant within the immediate future is not now in prospect.

Flood Damage

Flood damage on the Rio Grande in Colorado between Creede and Alamosa has been limited. Occasionally the head gates and diversion dams of some of the canals have been damaged and prolonged high water in the river at Alamosa has raised the ground waters beneath that city high enough to flood cellars and overload the sewage system.

Below Alamosa, the flooding of larger areas of farm land near the mouth of La Jara Creek and the Conejos River has occurred frequently but the resulting benefits to meadows and pastures have sometimes been as great as the damage to other areas.

The construction of Wagon Wheel Gap Reservoir cannot be expected to alleviate flood conditions to any great extent unless a considerable amount of its capacity is set aside for flood regulation alone.

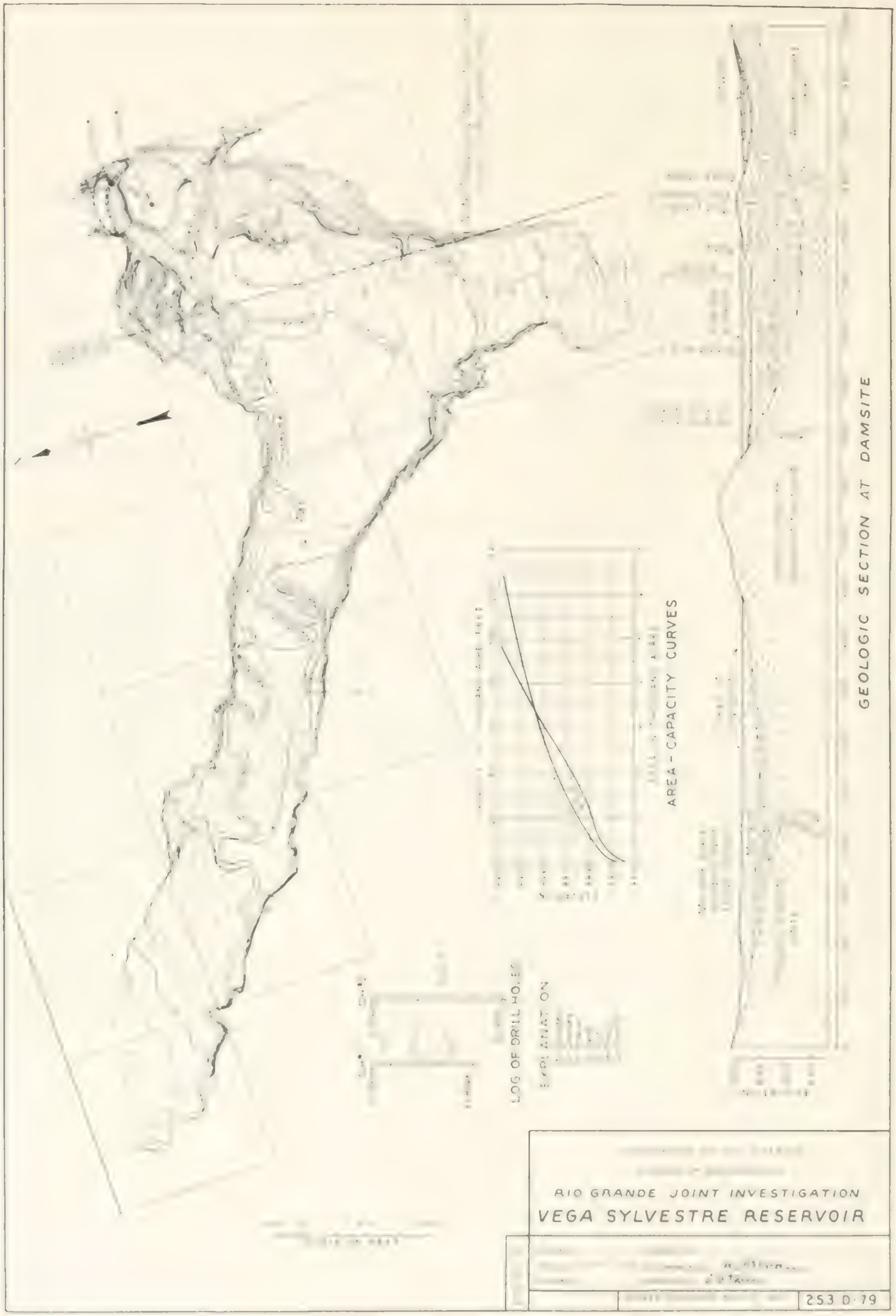

LOG OF DRILL HOLES
EXPLANATION
AREA - CAPACITY CURVES
GEOLOGIC SECTION AT DAMSITE
RIO GRANDE JOINT INVESTIGATION
VEGA SYLVESTRE RESERVOIR
253 D 79

TABLE 18.—[illegible]

Year	[illegible] (releases) [illegible]	[illegible] full[2]	[illegible]	[illegible]	[illegible]	Mean reser- [illegible] for year in [illegible]	Power output in 1,000,000 kilowatt-hours [illegible]	[illegible]
1910	432	161	593	[illegible]	[illegible]	976	0.270	[illegible]
1911	279	230	[illegible]	509	[illegible]	[illegible]	[illegible]	130.0
1912	398	229	627	610	[illegible]	1,003	.272	174.2
1913	419	18	437	437	0	[illegible]	.271	[illegible]
1914	413	67	480	477	3	1,003	.272	129.7
1915	425	52	477	477	[illegible]	1,003	.272	129.7
1916	310	205	515	515	0	1,003	.272	134.1
1917	346	282	[illegible]	[illegible]	72	[illegible]	.272	149.0
1918	437	0	437	437	0	[illegible]	.271	[illegible]
1919	353	62	415	415	0	1,003	.272	[illegible]
1920	271	345	616	[illegible]	64	1,003	.272	149.1
1921	[illegible]	[illegible]	711	609	[illegible]	1,003	.272	157.9
1922	275	317	[illegible]	[illegible]	18	[illegible]	.272	173.2
1923	[illegible]	[illegible]	467	467	0	[illegible]	.272	[illegible]
1924	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	.271	[illegible]
1925	387	0	387	387	0	[illegible]	.272	105.3
1926	[illegible]	22	[illegible]	[illegible]	0	[illegible]	.272	[illegible]
1927	[illegible]	250	[illegible]	[illegible]	0	1,003	.272	137.2
1928	395	97	492	492	0	991	.271	141.0
1929	281	161	442	442	0	1,003	.272	113.6
1930	460	0	460	460	0	984	.270	131.3
1931	512	0	512	512	0	792	.250	130.5
1932	248	0	248	248	0	907	.263	65.1
1933[3]	434	0	434	434	0	891	.261	113.8
Total	8,748	3,286	12,034	11,755	279	[illegible]		3,179.7
Mean	364.5	136.9	501.4	489.8	11.6	981.6	.270	132.5

[1] Release required to make up total demand at Del Norte of 600,000 acre-feet.
[2] Released through turbines and usable for power.
[3] January to September, inclusive, only.

Based on reservoir operation study by R. J. Tipton.

Vega Sylvester Reservoir

Summary of data:

Storage capacity	240,000 acre-feet.
Spillway capacity	15,000 second-feet.
Regulated Outlet capacity at 45-foot head.	5,000 second-feet.
Top of dam, elevation	8,970.
Maximum water surface, elevation	8,962.
Height of dam above stream bed	125 feet.
Total estimated cost, dam and reservoir.	$4,825,879 maximum.
Reservoir topography and geologic section.	Fig. 143.
General plan and sections	Fig. 144.
Preliminary estimate	Table 19.

General

The Vega Sylvester Reservoir is generally considered an alternative for the Wagon Wheel Gap Reservoir which, although not so effective in control of the Rio Grande, would provide a large measure of storage control at much less cost than the Wagon Wheel Gap Reservoir. It is about 17 miles above that site, also on the main stream, but with several important tributaries entering between. The drainage area is 530 square miles, mostly at high altitudes. San Luis Valley interests had tentatively decided upon a storage capacity of 240,000 acre-feet as best suited to valley needs and the designs submitted are for that capacity. The Bureau of Reclamation, in accordance with the program of work for this investigation, has not made a study of waters storable nor of the possible utilization of storage releases.

The proposed dam is located about 11 miles southwest of Creede, Colo., the nearest railroad point, in Mineral County, Colo. Colorado State Highway No. 149 from Creede to Lake City passes through portions of the reservoir. Approximately 7 miles of this highway would have to be reconstructed and a small mileage of secondary roads would also be affected.

The State engineer furnished maps of the reservoir and dam site, together with logs of several holes heretofore drilled.

Much of the basin is a mountain meadow used for pasture and wild hay, but its chief value is for recreational and fishing purposes.

Geology

The dam for Vega Sylvester Reservoir is only about 4 miles above the flow line of Wagon Wheel Gap Reservoir. Regional geology as described for that area is equally applicable to this with the exception that the only extrusive formation found in the basin itself is the earliest Conejos andesite, and the later Creede alluvium. Subsequent to the deposition of the Creede formation, Wisconsin glaciers occupied the new valley and deposited large quantities of loose detritus in the form of moraines and outwash. Continued recent erosion has somewhat modified these deposits, forming terraces in the outwash and channels across the moraines.

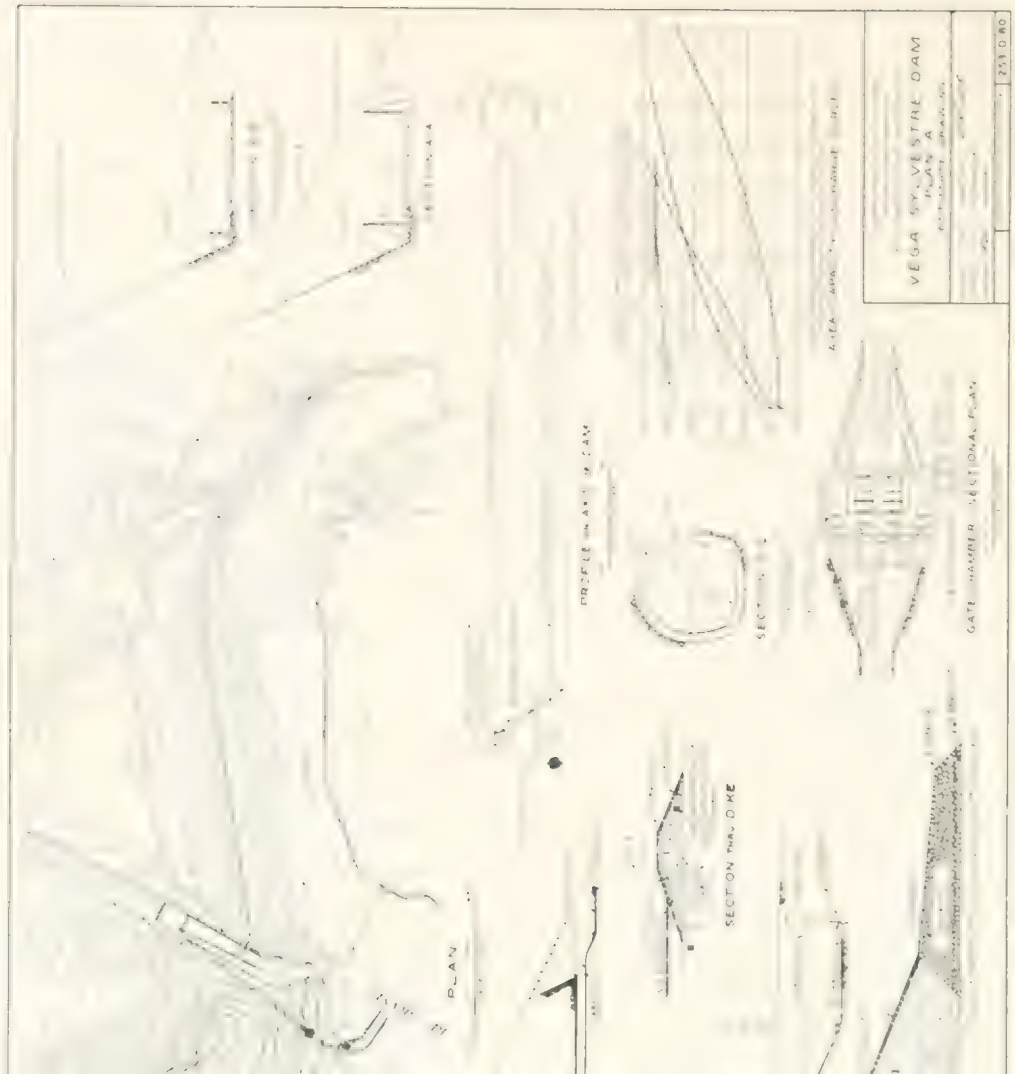


FIGURE 144

The basin is a normal erosional feature, carved from a rather complex but ordinarily impervious rock complex. (Conejos andesite, Creede siltstones.) The horizontal Creede siltstones are heavily mantled with river gravels and with glacial terrace gravels, largely derived from moraine and other glacial debris. All these detrital materials are extremely porous and unconsolidated, so that considerable ground storage can be expected.

There is no reason to suspect an unsatisfactory reservoir basin above the dam site. Normal spring and seep occurrences indicate a water table tributary to the river with remote chance for an inclined or perched condition.

The ancestral Rio Grande Valley was carved from substantially horizontal volcanic flows. The Creede sedimentaries were likewise deposited essentially horizontal.

It is known that considerable faulting crosses the valley at approximately right angles to the river, below and possibly above the dam site. Effects of these movements are undoubtedly reflected in the fractured and displaced state of sections of the left abutment andesite. On the whole, the central knob is horizontal but detailed work will be required to interpret local irregularities.

Although the block faulting is believed to have occurred after Creede deposition, it is doubtful whether this will have any detrimental effect on its impervious character, especially as the fault zones do not follow the river but cut obliquely across.

The Creede tuffs, ashes, shales, sandstones, and conglomerates are abundantly exposed below the dam site. In general, toward the center of the valley the deposits are shaly, well stratified and apparently part of a lake deposit. Marginal facies are sometimes sandstone or even conglomerate. Numerous travertine or hot spring deposits are found, one of which outcrops shortly above the dam site. The Creede sedimentaries when ever encountered can be considered adequately impervious and competent.

The rock forming the left abutment is believed to be the so-called "Conejos" andesite of the Tertiary volcanic series. It is a dark, fine-grained flow rock with visible crystals of feldspar, biotite, and pyroxene. In areas, it is somewhat porphyritic. It is uniformly hard but is somewhat fractured; the latter condition is sometimes accentuated in shear zones. This flow is one of the oldest members of a long series of extrusives.

On the extreme left, the saddle across which the Lake City, Creede road passes must serve as a natural dam. This depression is filled by a parallel series of lateral or terminal moraines which rise to such a height as to require the addition of only low additional dikes. The moraines are similar to those on the right abutment. A pit exposed a heterogeneous assemblage of poorly compacted boulders, cobbles, gravel, and sand. The material caved and raveled easily, necessitating careful timbering. In all probability it is quite porous. It is said that when irrigation occurs on the neighboring flats, ponds form in several of the lower glacial depressions. The depth to a cut-off is unknown and either Creede siltstone or andesite may form the underlying basement. The valley floor downstream from these moraines is flat and in all probability is heavily mantled with loose porous terrace gravels topped by a thin veneer of soil.

On the right abutment, rock is so deep that it cannot practicably be reached with a cut-off. Support and impervious properties must rely upon the character of the glacial moraine which is composed of assemblages of unstratified boulders, cobbles, gravel, sand, and minor silt. A test pit penetrating the right abutment material indicated a moderately firm deposit for the first 25 feet with a gradational change into looser, porous gravels to a depth of 100 feet. Continued with a drill hole, the same material was encountered to 200 feet. Water was encountered at 97 feet, or 13 feet above the river. A characteristic, thin clay-silt coating is found covering the cobbles and pebbles, a feature not found in the terrace and river gravels. These morainal deposits are remarkably uniform in character both horizontally and vertically. Lensed structures are generally lacking and if it were not for the surface topographic expressions, identification would be difficult. As a rule, moraine material is somewhat compact and relatively impermeable but these deposits are different. It is evident that they are very porous, only slightly better than loose river gravels. With a 4-foot depth of water in pit no. 2, the continuous outflow was 33 gallons per minute.

The terrace gravels are believed to be largely derived from glacial detritus as the stream reworked these deposits and spread them out as stratified river gravels. In this process much of any original silt content was lost, but large boulders were not moved so that the resulting deposits are extremely loose and porous. Pit no. 1 in this gravel would not stand unsupported for more than 3 feet. At 15 feet, the hole had to be abandoned. These gravels are now found above the present stream bed as terrace flats and remnants.

In the river bed, loose porous gravels will be encountered for at least 100 feet beneath the river and may continue to 150 or 200 feet. Drilling prior to that by the Bureau suggested that the clay content becomes predominant with depth. This conclusion is not borne out by the Bureau's examination and must be discounted until justified by the results of further drilling. Neither drill hole no. 1 nor no. 2 shows any evidence of this condition, although it must be recognized that their positions are not ideally located for this determi-

TABLE 19.—*Vega-Sylvestre Dam, preliminary estimate, plan A, December 1936*

[Normal water surface elevation, 8,962; spillway capacity, 15,000 cubic foot-seconds; outlet capacity, 5,000 cubic foot-seconds; storage capacity, 240,000 acre-feet]

[illegible]

Item No.	Item	Quantity: Amount	Quantity: Unit	Material and labor fur- [illegible]: Unit cost	Material and labor: Total cost	[illegible] the Government: Unit cost	the Government: Total cost	Summary: Unit cost	Summary: Total cost
1	[illegible]	[illegible]			$20,000				$20,000
2	[illegible]	[illegible]	Cubic yard	$0.30	75,000			[illegible]	75,000
[illegible]	[illegible]	350,000	Cubic yard	.30	105,000			.30	105,000
[illegible]	[illegible]	158,000	Cubic yard	.30	47,400			.30	47,400
[illegible]	Excavation, rock for spillway and for tunnel inlet and outlet	241,000	Cubic yard	1.00	241,000			1.00	241,000
[illegible]	[illegible]	26,000	Cubic yard	[illegible]	[illegible]			8.00	208,000
[illegible]	[illegible]	230,000	Cubic yard	[illegible]	[illegible]			.25	[illegible]
[illegible]	[illegible]	250	Cubic yard	[illegible]	1,250			[illegible]	[illegible]
[illegible]	Excavation, common, in borrow pits and transportation to [illegible]	5,050,000	Cubic yard	[illegible]	[illegible]			.25	1,262,250
[illegible]	Excavation, rock, in borrow pits and transportation to [illegible]	12,000	Cubic yard	.75	[illegible]			.75	[illegible]
[illegible]	[illegible]	20,000	Cubic yard	[illegible]	[illegible]			[illegible]	10,000
[illegible]	[illegible]	4,500,000	Cubic yard	[illegible]	[illegible]			.10	450,000
[illegible]	[illegible]	300,000	Cubic yard	.30	[illegible]			.30	90,000
[illegible]	[illegible]	90,000	Cubic yard	.50	[illegible]			.50	[illegible]
[illegible]	[illegible]	2,000	Cubic yard	1.00	2,000			1.00	2,000
[illegible]	[illegible]	1,600	Linear foot	.70	[illegible]	[illegible]	$1,120	1.40	2,240
17	[illegible]	6,200	Linear foot	[illegible]	[illegible]	[illegible]	3,720	1.20	7,440
[illegible]	[illegible]	[illegible]	Linear foot	[illegible]	[illegible]	[illegible]	[illegible]	1.00	[illegible]
[illegible]	[illegible]	1,000	Linear foot	[illegible]	[illegible]			1.00	1,000
[illegible]	[illegible]	20,000	Linear foot	[illegible]	[illegible]			[illegible]	20,000
21	[illegible]	[illegible]	Linear foot	1.75	[illegible]			[illegible]	875
22	[illegible]	1,000	Linear foot	[illegible]	2,500			2.50	[illegible]
[illegible]	[illegible]	7,000	[illegible]	[illegible]	[illegible]	.10	[illegible]	.20	[illegible]
[illegible]	[illegible]	[illegible]	Cubic foot	1.00	22,000	.60	13,200	1.60	[illegible]
[illegible]	[illegible]	1,000	[illegible]	1.00	1,000	[illegible]	[illegible]	1.50	1,500
[illegible]	[illegible]	200	[illegible]	12.00	2,400	7.00	[illegible]	19.00	3,800
[illegible]	[illegible]	470	Cubic yard	17.50	8,225	7.50	[illegible]	[illegible]	11,750
[illegible]	[illegible]	[illegible]	Cubic yard	13.00	58,500	7.00	[illegible]	20.00	90,000
[illegible]	[illegible]	5,500	Cubic yard	15.00	82,500	7.50	[illegible]	22.50	123,750
30	[illegible]	3,450	Cubic yard	10.00	34,500	7.00	24,150	17.00	58,650
[illegible]	Concrete in spillway and outlet works channel, except [illegible]	4,300	Cubic yard	12.00	51,600	7.00	30,100	19.00	81,700
[illegible]	[illegible]	330	Cubic yard	20.00	6,600	7.50	2,475	27.50	9,075
33	[illegible]	1,300	Cubic yard	14.00	18,200	7.50	9,750	21.50	[illegible]
[illegible]	[illegible]	2,200,000	[illegible]	.025	55,000	.035	77,000	.06	132,000
35	[illegible]	1,500	[illegible]	.30	450	.30	[illegible]	.60	[illegible]
[illegible]	[illegible]	100,000	[illegible]	.10	10,000			.10	10,000
[illegible]	[illegible]	[illegible]	Square yard	.60	4,140			[illegible]	4,140
[illegible]	Construction of outlet works operating house, except con- [illegible]	(1)			[illegible]		[illegible]		3,000
[illegible]	[illegible]	140,000	[illegible]	[illegible]	[illegible]	.07	9,800	.10	14,000
[illegible]	Installing high-pressure hydraulically operated slide gates [illegible]	320,000	[illegible]	[illegible]	[illegible]	.12	38,400	[illegible]	48,000
[illegible]	[illegible]	[illegible]	Pound	[illegible]	13,840	.15	51,900	.19	65,740
42	[illegible]	12,000	Pound	.10	1,200	.35	4,200	.45	5,400
[illegible]	[illegible]	368,400	Pound	.04	14,736	.23	84,732	[illegible]	99,468
[illegible]	[illegible]	70,000	Pound	.03	2,100	[illegible]	7,000	[illegible]	9,100
[illegible]	[illegible]	(1)					[illegible]		13,500
46	[illegible]	[illegible]	Pound	[illegible]	2,400	.20	12,000	.24	14,400
[illegible]	Installing metal stairway, walkway, and grating	10,000	[illegible]	.10	1,000	.12	1,200	.22	2,200
[illegible]	[illegible]	[illegible]	Pound	.10	500	.15	750	[illegible]	1,250
[illegible]	[illegible]	30,000	Pound	[illegible]	3,000	.10	3,000	.20	6,000
[illegible]	[illegible]				2,000		12,500		14,500
[illegible]	[illegible]	[illegible]					40,000		40,000
	[illegible]				[illegible]		[illegible]		3,589,628
	[illegible]								538,444
	[illegible]								4,128,072
	[illegible]								5,000
	[illegible]								247,684
	[illegible]								[illegible]
	[illegible]								103,202
	[illegible]								4,545,879
	[illegible]		5,000 acre			[illegible]			175,000
	[illegible]					[illegible]			105,000
	[illegible]								[illegible]

(1) [illegible]

[illegible]

nation. It is possible that some of the material listed as "heavy with clay", in the past drilling, was in reality the Creede formation. Artesian conditions point toward this belief.

Most of the holes in past drilling on the lower axis encountered artesian water. The origin of this is not clear due to the uncertainty of the character of the materials that were penetrated and when and where the flow was first encountered.

Hole no. 1 on the upper axis encountered Creede formation at 101 feet. It is significant that the water table remained at 42 feet until a depth of 101 feet was reached. Later a slow rise was noted, fed in all probability from an aquifer in the Creede silts. However, no gravel zones were encountered in the Creede formation. It is suggested that if the hole had been deeper some such member would have been encountered.

Such a conclusion suggests that Creede formation may have been penetrated at the lower axis. Flow from these holes was measured at 2–3 gallons per minute. The artesian pressure at the river is small, estimated about 2–5 pounds per square inch.

Geologically, the dam site must be classified as a poor one as it requires excessive corrective measures to overcome unsatisfactory characteristics. Much more prospecting must be done before the limitations of safe and economical design can be determined.

Design Problems

In all, five different designs and estimates have been made to utilize the dam site, beginning with a dam across the river bottom on the lowest axis and successively swinging the axis upstream in a radial direction from the left abutment, in order to utilize the terrace upstream from the shortest axis. If there were no uncertainties concerning ability to drive sheet piling and its efficacy as a cutoff, the lower axis would probably be the best but recent experience has cast doubt upon the advisability of placing reliance on piling as a cutoff and opinions as to its practical use differ widely.

The most serious factor in any design is the amount of flow occurring under the dam and right abutment during reservoir operation. Information to aid in solving this problem is not sufficient in scope and could not be secured without the expenditure of several times the amount allotted for this study. Design of a safe dam is possible with present information but whether the reservoir will leak so badly as to materially impair the effectiveness of the reservoir, cannot be predicted.

The selection of a dam site in this locality is controlled by the relative values for foundation purposes, of the materials in the river bed, the terrace and the moraine on the right abutment. While these materials are all porous, they differ to some degree. The moraine material does contain a small amount of clay and is probably the least porous. The gravels in the river bed come next in porosity as they contain some sand but little, if any, clay. The reworked moraine material in the terrace is believed to contain very little sand or clay. Because of the many unsolved features, it is not considered advisable to recommend any one particular plan. Plan A herein described in some detail, is intended only as an approach to a final solution. This plan presents a scheme to secure a deep cutoff in the stable river gravels and avoid, so far as possible, dependency on the reworked moraine material. A blanket is carried upstream to increase percolation distances.

The plan contemplates a rolled earthfill and rockfill dam located in the wide portion of the river bottom where the overlying beds of resorted glacial and recent river gravels have been largely eroded. The upper portion of the upstream slope of the dam has a 3:1 slope protected with 3 feet of riprap while the lower portion consists of a long blanket with variable slopes. The downstream slope varies from 2½:1 in the upper portion with variable slopes approximating 12:1 in the lower portion. The upper portion of the rock fill is 3 feet thick and the lower portion varies in thickness to a maximum of about 35 feet. The central and earth blanket portions of the dam are composed of impervious material grading into pervious material at the outer slopes. The cutoff trench has a bottom width of 20 feet and 1:1 side slopes with a depth of approximately 30 feet. A concrete cut-off wall will be constructed in the bottom of the trench at the left abutment where rock is encountered. The rock at the left abutment will be grouted beneath the cut-off wall and elsewhere, as required.

Left Ridge Dike

A long low dike is required at a low section in the reservoir west of the dam. Rapid seepage of irrigation water at this point indicates high porosity and it is very questionable whether leakage through the foundation materials under the dike could be reduced materially at a reasonable cost. A cut-off trench with a 10-foot bottom width and 20-foot depth is provided and is considered the maximum size of trench justified by the height of the dike.

Spillway

The spillway is located on the left abutment in the andesite rock. Outflow is controlled by three 20- by 17-foot radial gates having a discharge capacity of 15,000 second-feet. The channel is concrete-lined

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throughout and terminates in a combination stilling basin for the spillway and the outlet works. A long outlet channel will be required to connect with the river channel.

Outlet and Diversion

The outlet and diversion tunnel is located in the left abutment. The 18-foot diameter horseshoe tunnel extends from the trash-rack structure to the spillway stilling basin except for a section at the gate chamber which is widened to provide for four outlet conduits. The two outer conduits are controlled by two sets of 5- by 6-foot hydraulically operated slide gates and the two inner conduits are controlled by 84-inch needle valves and 96-inch ring follower gates. A diversion requirement of 4,000 second-feet is provided with the gates installed and the needle valves omitted until storage is begun.

Construction Materials

Test pits have shown a sufficient supply of suitable materials for construction of the earth embankment available at a distance of approximately three-quarters of a mile below the dam site on the right bank. The spillway and outlet tunnel excavation will provide the major portion of rock embankment for the riprap and rock fill portions of the dam. It is believed that sand and gravel aggregate for concrete is available near the dam site but no pits have been prospected.

Right-of-Way

The area flooded by the reservoir is a mountain meadow used for pasture only, but in addition, has a recreational value for fishing. There are few buildings in the area. Seven miles of the Creede-Lake City highway will need to be relocated on more difficult terrain than the present location.